Technical Memorandum:

Delta Risk Management Strategy (DRMS) Phase 1

Topical Area:

Flood Hazard

Final

Prepared by:
URS Corporation/Jack R. Benjamin & Associates, Inc.

Prepared for:
California Department of Water Resources (DWR)

March 4, 2008

December 5, 2008

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Subject: Delta Risk Management Strategy
Final Phase 1 Technical Memorandum – Flood Hazard

Dear Mr. Bagheban:

We are providing the final Flood Hazard Technical Memorandum (TM) (dated March 4, 2008) for Phase 1 of the Delta Risk Management Strategy (DRMS) project. Members of the Steering Committee's Technical Advisory Committee and agency staff reviewed the second draft TM, and their comments were incorporated before the CALFED Independent Review Panel (IRP) review of the June 26, 2007, draft of the Risk Analysis Report. This final version of this TM addresses the IRP comments provided on the flood hazard sections of the Risk Analysis Report.

This document was prepared by Dr. Thomas MacDonald, Senior Hydrologist (URS), Mr. Phil Mineart, Senior Hydrologist (URS), and Mr. Douglas De Vries, Senior Water Resources Engineer (URS). Drs. C. Allin Cornell (Professor Emeritus, Stanford University) and Ram Kulkarni, Principal Engineer (URS), provided guidance in applying risk concepts to the flood hazard analysis. Drs. Said Salah-Mars (URS) and Marty McCann (Jack R. Benjamin & Associates, Inc.) reviewed this TM. Internal peer review was provided in accordance with URS' quality assurance program, as outlined in the DRMS project management plan.

Sincerely,

Said Salah-Mars

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Topical Area: Flood Hazard

Preamble

In response to Assembly Bill (AB) 1200 (Laird, chaptered, September 2005), the California Department of Water Resources (DWR) authorized the Delta Risk Management Strategy (DRMS) project to perform a Risk Analysis of the Sacramento–San Joaquin Delta (Delta) and Suisun Marsh (Phase 1) and to develop a set of improvement strategies to manage those risks (Phase 2).

AB 1200 amends Section 139.2 of the Water Code to read: "The department shall evaluate the potential impacts on water supplies derived from the Sacramento–San Joaquin Delta based on 50-, 100-, and 200-year projections for each of the following possible impacts on the Delta:

1. Subsidence
2. Earthquakes
3. Floods
4. Changes in precipitation, temperature, and ocean levels
5. A combination of the impacts specified in paragraphs (1) to (4) inclusive."

AB 1200 also amended Section 139.4 to read: "(a) The Department and the Department of Fish and Game shall determine the principal options for the Delta. (b) The Department shall evaluate and comparatively rate each option determined in subdivision (a) for its ability to do the following:

1. Prevent the disruption of water supplies derived from the Sacramento–San Joaquin Delta.
2. Improve the quality of drinking water supplies derived from the Delta.
3. Reduce the amount of salts contained in Delta water and delivered to, and often retained in, our agricultural areas.
4. Maintain Delta water quality for Delta users.
5. Assist in preserving Delta lands.
6. Protect water rights of the "area of origin" and protect the environments of the Sacramento–San Joaquin river systems.
7. Protect highways, utility facilities, and other infrastructure located within the Delta.
8. Preserve, protect, and improve Delta levees.…"

To meet the requirements of AB 1200, the DRMS project has been divided into two parts. Phase 1 involves the development and implementation of a Risk Analysis to evaluate the impacts of various stressing events on the Delta. Phase 2 evaluates the risk reduction potential of alternative options and develops risk management strategies for the long-term management of the Delta.

As part of the Phase 1 work, 12 technical memoranda (TMs), which address individual topical areas, and one risk report have been prepared. This TM addresses the flood hazard issues that are considered in Phase 1. The TMs and the topical areas covered in the Phase 1 Risk Analysis are as follows:

1. Geomorphology of the Delta and Suisun Marsh
2. Subsidence of the Delta and Suisun Marsh
3. Seismology of the Delta and Suisun Marsh
4. Climate Change in the Delta and Suisun Marsh
5. Flood Hazard of the Delta and Suisun Marsh
6. Wind-Wave Hazard of the Delta and Suisun Marsh
7. Levee Vulnerability of the Delta and Suisun Marsh
8. Emergency Response and Repair of the Delta and Suisun Marsh Levees
9. Hydrodynamics, Water Quality, and Management and Operation of the Delta and Suisun Marsh (Water Analysis Module)*
10. Ecosystem Impacts to the Delta and Suisun Marsh
11. Impact to Infrastructure of the Delta and Suisun Marsh
12. Economic Consequences to the Delta and Suisun Marsh

*Two separate topical areas—the Hydrodynamics topical area and the Water Management topical area—were combined into one TM because of the strong interaction between them. The resulting TM is referred to as the Water Analysis Module (WAM).

The work products described in all of the TMs are integrated in the DRMS Risk Analysis. The results of the Risk Analysis are presented in a technical report referred to as:

13. Risk Analysis Report

Taken together, the Phase 1 TMs and the Risk Analysis Report constitute the full documentation of the DRMS Risk Analysis.

The Business-as-Usual Delta and Suisun Marsh: Assumptions and Definitions

To carry out the DRMS Phase 1 analysis, it was important to establish some assumptions about the future “look” of the Delta. To address the challenge of predicting the impacts of stressing events on the Delta and Suisun Marsh under changing future conditions, DRMS adopted the approach of evaluating impacts absent major future changes in the Delta as a baseline. Thus, the Phase 1 work did not incorporate or examine proposals for Delta improvements. Rather, Phase 1 identified the characteristics and problems of the current Delta (as of 2005), with its practices and uses. This approach, which allows for consideration of pre-existing agreements, policies, funded projects, and practices, is referred to as the “business-as-usual” (BAU) scenario. Defining a BAU Delta is necessary because one of the objectives of this project is to estimate whether the current practices of managing the Delta (i.e., BAU) are sustainable for the foreseeable future. The results of the Phase 1 Risk Analysis based on the BAU assumption not only maintained continuity with the existing Delta, but also served as the baseline for evaluating the risk reduction measures considered in Phase 2.

The existing procedures and policies developed to address “standard” emergencies in the Delta, as covered in the BAU scenario, do not cover some of the major (unprecedented) events in the Delta that are evaluated in the Risk Analysis. In these instances, prioritization of actions is based on (1) existing and expected future response resources and (2) the highest value of recovery/restoration given available resources.

This study relied solely on available data. In other words, the effects of stressing events (changing future earthquake frequencies, future rates of subsidence given continued farming practices, the change in the magnitude and frequency of storm events, and the potential effects of global warming) on the Delta and Suisun Marsh levees were estimated using readily available engineering and scientific tools or based on a broad and current consensus among practitioners. Using the current state of knowledge, the DRMS project team made estimates of the future magnitude and frequency of occurrence of the stressing events 50, 100, and 200 years from now to evaluate the change in Delta risks into the future.

Because of the limited time available to complete this work, no investigation or research was conducted to supplement the current state of knowledge.

Perspective

The analysis results presented in this TM do not represent the full estimate of risk for the Delta and Suisun Marsh. The full estimate of risk is the probable outcome of the hazards (earthquake, floods, climate change, subsidence, wind waves, and sunny day failures) combined with the conditional probability of the subject outcome (levee failures, emergency response, water management, hydrodynamic response of the Delta and Suisun Marsh, ecosystem response, and economic consequences) given the stressing events. A full characterization of risk is presented in the Risk Analysis Report. In that report, the integration of the initiating (stressing) events, the conditional probable response of the Delta levee system, and the expected probable consequences are integrated to develop a complete assessment of risk to the Delta and Suisun Marsh. In this context, the subject of this TM is one element of the Risk Analysis.

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Acronyms and Abbreviations

CDEC	California Data Exchange Center
cfs	cubic feet per second
Delta	Sacramento–San Joaquin River Delta
DRMS	Delta Risk Management Strategy
DWR	Department of Water Resources
gfdl	Geophysical Fluid Dynamics Laboratory
LPIII	Log Pearson Type III
mi^2	square mile
MSL	mean sea level
NAVD 88	North American Vertical Datum of 1988
ncar	National Center for Atmospheric Research
NGVD 29	National Geodetic Vertical Datum of 1929
NOAA	National Oceanic and Atmospheric Administration
pcm	Parallel Climate Model
PMF	Probable Maximum Flood
RI	remaining inflow
SRES	Special Report on Emissions Scenarios
TDI	Total Delta Inflow
USBR	U.S. Bureau of Reclamation
USGS	U.S. Geological Survey
WY	water year

Topical Area: Flood Hazard

1. Introduction

1.1 Background

Damages in the Sacramento–San Joaquin River Delta (Delta) could result from earthquakes, floods, subsidence, animal burrowing activity, and other natural events. Hydrologic events could also result in major damages throughout the Delta. Knowledge of the magnitude, characteristics, and frequency of various hydrologic events is needed as input to develop the Delta Risk Management Strategy (DRMS) risk model. Specifically, estimates of the frequencies of concurrent water-surface elevations throughout the Delta are needed to evaluate potential Delta flood hazards.

1.2 Purpose

One failure mechanism that is analyzed in the Risk Analysis model is levee failure due to the effects of hydrologic events. For each hydrologic event the information needed includes the frequency of the event, an estimate of the uncertainty associated with that frequency, and the water-surface elevation (stage) in the Delta associated with that event. As described in Section 2 of this memorandum, an event is defined by the magnitude of the Total Delta Inflow (TDI). Since the stage in the Delta is a function of not only the TDI but also the locations of the inflows, it is necessary to distribute the TDI among the different inflow sources. Each distribution of inflows has a probability associated with it.

The purpose of the analyses presented in this technical memorandum is to develop a method for estimating the hydrologic characteristics in the Delta that are needed as input to the Risk Analysis, such as inflow magnitudes, patterns, water-surface elevations, and their probabilities and uncertainties of occurrence. As part of the DRMS Risk Analysis, a broad range of hydrologic events, including the uncertainty in the analysis, must be considered. To support the Risk Analysis (that is, to generate the hydrologic inputs to the Risk Analysis), an approach is required that is simple and robust.

The flow and stage data and procedures developed in this study were specifically developed as inputs to the Risk Analysis. We are not aware of any other studies, such as the U.S. Army Corps of Engineers Comprehensive Study (USACE 2002), that consider a probabilistic risk analysis of levee failure in the Delta. The purposes of previous studies have been considerably different from the purpose of this study, and therefore the information contained in these previous studies did not appear to be relevant.

It is worth noting that the purpose of this study was not to develop frequency information on stages in the Delta. Rather, the purpose of this study was to develop a relationship for flood stages in the Delta for a given occurrence probability of Delta inflow.

For a given Delta inflow, the stage everywhere in the Delta was predicted. The probability of those stages occurring (or of being exceeded) may or may not be equal to the probability of occurrence of the Delta inflow and could be different for different parts of the Delta. The procedures used in the Risk Analysis did not require the selection (or knowledge) of the probability of occurrence of a particular stage in the Delta. This approach is a departure from typical flood studies, and that distinction helps explain why no other studies were identified as having relevant information.

1.3 Scope

The data and analyses used for estimating the frequency of occurrence of water-surface elevations in the Delta are addressed in the following sections:

- Section 2: Hydrologic Data
- Section 3: Flow-Frequency Analyses
- Section 4: Delta Inflow Patterns
- Section 5: Delta Water-Surface Elevations
- Section 6: Future Hydraulic Risks
- Section 7: Summary and Verification
- Section 8: References

Appendix A provides tables and figures that show the results of the flood stage equations used in this analysis.

Appendix B provides (1) the DRMS Steering Committee/agency comments on the draft Flood Hazard Technical Memorandum and (2) the CALFED Science Program Independent Review Panel comments on the draft Risk Analysis Report that apply to the Flood Hazard Technical Memorandum. Appendix B also provides the responses to these two sets of comments.

2. Hydrologic Data

2.1 Tide Data

Tides and the magnitudes and patterns of inflow influence water-surface elevations in the Delta and therefore must be considered. The tide data used in these analyses are the water-surface elevation measurements at the San Francisco tide station (National Oceanic and Atmospheric Administration [NOAA] station 9414290). For purposes of these analyses, the water-surface elevation measurements at the San Francisco station are referred to as tides and include astronomical tides, storm surges, and other factors influencing the water-surface elevation. The San Francisco tide station was chosen for its long record of unbroken tide data, which dates back about 150 years. Tide levels at this station are relatively independent of inflows into the Delta and provide a geographically relevant measure of tailwater conditions that influence water levels in the Delta.

2.2 Delta Inflow and River Stage Data

For the Risk Analysis, it is necessary to define the hydrologic events (and their probabilities) that will be included in the analysis. Because the Risk Analysis is estimating the probability of occurrence of both single and multiple levee failures, it is not sufficient to define an occurrence based on the inflow from a single river (e.g., the Sacramento River), as a levee failure or failures could potentially occur anywhere in the Delta. One approach would be to analyze the joint probability of occurrence of different events on the major Delta inflows (e.g., the probability of a 100-year event occurring on the Sacramento River that is simultaneous with a 100-year event on the San Joaquin River and a 100-year event on the Cosumnes River, etc.). Although the probabilities of a joint occurrence could be calculated, the meaning of these probabilities would be unclear. To cover all possible combinations using this approach would result in a large number of events (e.g., for ten return periods for the four major inflows, the result would be 10,000 combinations), all of which would have small probabilities of occurrence. To simplify the problem, a single parameter was selected to define an event: the TDI. When referring to an event with a 1 percent annual occurrence probability, the meaning is that the total inflow into the Delta is exceeded only 1 percent of the time. Average daily inflows into the Delta are readily available from the California Department of Water Resources (DWR) website for the 50 water years (WYs) from October 1, 1955, through September 30, 2005 (WY 1956 through WY 2005). Although much longer records of stream flows may be available for some of the Delta tributaries, data for all tributaries are either not available or would require considerable analyses and adjustment to provide a consistent, reliable, complete, and continuous record of inflow. A working premise of the DRMS project is that analyses should rely on existing data sets/sources.

Data from the DWR website include average daily inflows for all major streams entering the Delta and the total inflow into the Delta (DWR 2006). The major streams or stream groups included in the data set are the Sacramento River, Yolo Bypass, Cosumnes River, Mokelumne River, San Joaquin River, and miscellaneous streams. Flows in miscellaneous streams are primarily Calaveras River flows. The locations of the flow measuring stations used in the analysis are shown in Figure 2-1. Measured average daily inflows into the Delta are summarized graphically on Figure 2-2. Figure 2-2a presents total inflows into the Delta for the period of record. Figure 2-2b presents inflows from the Sacramento River and Yolo Bypass, the major contributors to the total inflow (>80 percent). Figure 2-2c presents inflows from the San Joaquin River, the second-largest contributor to total inflow (>10 percent).

Water-surface elevations in the Delta were estimated from data on historical water levels measured at selected Delta gauging stations. Water levels, or stages, at the selected gauging stations were then used to interpolate stages at intermediate locations in the Delta. The California Data Exchange Center (CDEC) provides information on an extensive hydrologic data collection network that includes automatic river stage sensors in the Delta. River stage data are provided primarily from the stations maintained by the DWR and U.S. Geological Survey (USGS). The stage data can be downloaded from the CDEC website (CDEC no date, http://cdec.water.ca.gov/queryCSV.html.). A detailed discussion of the stage data is given in Section 5.

2.3 Probable Maximum Flood Inflow Data

For the DRMS studies, inflow-frequency analyses of measured annual peak total daily inflows were used to provide estimates of peak inflows that could occur under extreme hydrologic conditions. However, the inflow-frequency estimates are based on statistical analyses of a limited number of years of data and do not recognize that an upper limit to the severity of hydrologic events is controlled by the meteorological conditions of the area. For purposes of these studies, the upper limit of inflow into the Delta was assumed to be an extreme event comparable in magnitude to the inflow resulting from a Probable Maximum Precipitation event over the Delta and tributary area (i.e., the Probable Maximum Flood [PMF] inflow into the Delta). The use of the PMF does not affect the probability distribution for flows into the Delta except for very extreme events (e.g., events with a probability of less than 1/100,000), so the results of the Risk Analysis are not affected by the PMF. PMF was included in the analysis to allow for the possibility of incorporating extreme events, should the need arise.

The PMF data used in these studies were obtained from the U.S. Bureau of Reclamation (USBR) (USBR 1986). USBR identified 61 historical extreme flood events that occurred throughout the United States and estimated the maximum runoff rates. PMF analyses were made for the watersheds associated with the historic flood events to determine if their PMF analysis methodology gives results that are consistent with historical data. These studies demonstrated that their methodology gave consistent and realistic estimates of PMF runoff. These analyses also provide data needed in the DRMS studies to estimate an upper limit of Delta inflows that that could occur.

In addition to these USBR PMF data, estimates of PMF peak runoff were obtained from the USBR website for five dams that are located in Northern California and/or are tributary to the Delta: Trinity, New Melones, Friant, Folsom, and Shasta (USBR no date, http://www.usbr.gov/dataweb/dams/).

The PMF estimates used in these studies are summarized in Table 2-1.

2.4 Analyses of Hydrologic Data

2.4.1 Period of Record for Analyses

One of the objectives of these studies is to develop estimates of the hydrologic characteristics of the Delta under current conditions in the tributary watersheds. Thus, it was necessary to examine the available Delta inflow data to determine if these data adequately reflect current watershed conditions or if the statistical characteristics of the data have significantly changed during the period of record due to new reservoirs in the watersheds, development in the watersheds, land use changes, or other factors.

As shown on Figure 2-2, the annual peak flows for the period from about 1987 to 1993 were smaller than for the period before 1987. These 6 years had below-average precipitation and had the longest period of below-average rainfall between 1955 and 2005. This 6-year period suggests that during the 50-year period of record, more drought years occurred in the recent period of record than in earlier years. It is therefore desirable to use the entire period of available inflow record to avoid or reduce any statistical bias caused by the 1987 to 1993 drought years.

Several dams and reservoirs, developments, and other changes have been constructed in the watersheds tributary to the Delta, and the impacts of these changes could have affected inflows into the Delta. Table 2-2 is a partial list of the dams and reservoirs that have been constructed in the tributary watersheds, along with the date of dam construction, the reservoir storage capacity, and the upstream drainage area controlled by the reservoir. Table 2-3 lists, in descending order of magnitude, the annual peak average daily Delta inflow during each WY of the period of record.

As shown on Figure 2-2, the incremental addition of reservoirs in the Sacramento or San Joaquin River watersheds between the beginning of the Delta inflow record (1955) and the essential completion of reservoir construction in the watersheds (1968 for the Sacramento River and 1978 for the San Joaquin River) did not have a noticeable impact on lowering annual peak day Delta inflows. Although new reservoirs constructed during the early years of the inflow record undoubtedly provided some incremental increase in flood protection (by reducing flows at and downstream from the new dams), it is possible that some of the flood attenuation provided by the new reservoirs may have occurred anyway due to floodplain storage, thereby reducing the apparent impact of the reservoirs on Delta inflows. This result is generally consistent with the results presented by Florsheim and Dettinger (2007), which showed that the pattern of levee breaks in the Delta was the same in the first half of the twentieth century (before major dam construction) as it was in the last half of the twentieth century (after major dam construction).

Figure 2-3a, 2-3b, and 2-3c are plots of some of the data presented in Tables 2-2 and 2-3. Figure 2-3a presents the cumulative amount of total reservoir storage in the Sacramento River watershed provided by major reservoirs (not all reservoirs in the watershed are accounted for) versus year and the magnitude and year of the 15 largest annual peak day Delta inflows from Sacramento River and Yolo Bypass. Figure 2-3b presents the same data as Figure 2-3a for the San Joaquin River watershed. It should be noted that Sacramento River and Yolo Bypass contributed, on average, approximately 90 percent and San Joaquin River contributed, on average, approximately 5 percent to the annual peak daily Delta inflow during the 50-year period of record, with the remaining inflows coming from Mokelumne, Cosumnes, and other rivers. Thus, changes in runoff characteristics from the Sacramento River watershed should have the most dramatic impact on Delta inflows. Figure 2-3c presents the cumulative drainage areas controlled by reservoirs for the Sacramento River and San Joaquin River watersheds by year.

As shown on Figure 2-3a, most of the major reservoirs in the Sacramento River watershed were completed by 1968, meaning 38 of the 50 annual peak day Delta inflows during the 50-year period of record represent approximate current watershed conditions. As also shown on Figure 2-3a, 11 of the largest 15 annual peak daily Delta inflows from Sacramento River and Yolo Bypass occurred during approximate current watershed conditions. The larger annual peak inflows have the greatest influence on estimated extreme event statistics.

As shown on Figure 2-3b, most of the major reservoirs in the San Joaquin River watershed were completed by 1979, meaning over half of the 50 annual peak daily Delta inflows during the 50-year period of record represent approximate current watershed conditions. As also shown on Figure 2-3b, 8 of the largest 15 annual peak daily Delta inflows from San Joaquin River occurred during approximate current watershed conditions.

As shown on Figure 2-3c, the percent of the drainage area controlled by reservoirs in the Sacramento River watershed is much greater than in the San Joaquin River watershed. Based on this difference, it would be expected that the reservoirs have a stronger influence on Delta inflows from Sacramento River than from San Joaquin River.

Figures 2-4, 2-5, and 2-6 illustrate the relative influence of reservoirs in the Sacramento River and San Joaquin River watersheds. Figure 2-4 presents the reservoir inflows and outflows that occurred in the Sacramento River watershed and the Delta inflows from the Sacramento River/Yolo Bypass during the major flood event of January 3, 1997. Similar data for the San Joaquin River watershed for the major flood events of January 3, 1997, and March 13, 1995, are presented in Figures 2-5 and 2-6, respectively. To develop a measure of the contribution to Delta inflow from only the reservoirs (excluding runoff from areas downstream of the reservoirs), inflows and outflows for each of the reservoirs in the watershed were lagged by the approximate time for the outflow to travel from the reservoir to the Delta (each reservoir has a lag time proportional to its distance from the Delta).

Figure 2-4 presents measured flows in the Sacramento River watershed during the major flood event of January 3, 1997. As shown on Figure 2-4a, reservoirs in the watershed significantly attenuated runoff from the upper portions of the watershed, reducing the combined peak reservoir inflows from about 675,000 cfs to about a 325,000 cfs outflow. Figure 2-4b shows that the 325,000 cfs reservoir outflow is increased by at least 185,000 cfs by runoff from downstream areas to give a peak Delta inflow of about 510,000 cfs. The cumulative watershed area upstream from the reservoirs is about 15,250 square miles (mi^2), or about 72 percent of the 21,250 square-mile watershed area tributary to the Delta (at Verona). These runoff and area estimates indicate that the peak runoff during the January 3, 1997, flood was about 44 cfs/mi^2 from the area above the reservoirs and about 31 cfs/mi^2 from the area below the reservoirs.

Reservoir inflows and outflows and Delta inflows for the San Joaquin River watershed during the January 1997 and March 1995 flood events are presented in Figures 2-5 and 2-6, respectively. Both of these figures show that the reservoirs significantly attenuate the inflows. However, the figures also show that Delta inflows are less than reservoir outflows during the 1997 event and about the same as the reservoir outflows during the 1995 event, indicating dam outflows plus the additional runoff that originates from below the dams is attenuated by floodplain storage before the flow reaches the Delta. Thus, inflows into the Delta are, to some extent, controlled by the capacity of the channel into the Delta.

During the 1995 and 1997 flood events, several levees along San Joaquin River are known to have failed due to lack of channel capacity. These failures diverted significant amounts of water into temporary storage on the floodplain. The San Joaquin River channel and associated bypass channels have a flood carrying capacity of less than 26,000 cfs upstream from the confluence of San Joaquin and Merced Rivers and only about 8,000 cfs upstream from the confluence of the river and Fresno Slough. It is therefore apparent that significant floodplain storage occurs and attenuates Delta inflows during major flood events. The cumulative watershed area upstream from the reservoirs is about 5,615 square miles, or about 41 percent of the 13,540 square-mile watershed area tributary to the Delta (at Vernalis).

The analyses of San Joaquin River runoff during the floods of January 1997 and March 1995 indicate that during major flood events the watershed reservoirs provide only a portion of the flood storage needed to attenuate flows to a level that can be transported into the Delta by the existing channel. Thus, increases in reservoir storage in the San Joaquin River watershed during the early portion of the period of record for these studies may not have significantly changed inflows into the Delta during major flood events but instead only reduced the amount of downstream floodplain storage. If this is the case, then the increases in reservoir storage that occurred during the study period can be ignored and the entire 50-year record of inflow for San Joaquin River can be used without adjustment. It is believed that, to some extent, this same argument can be made for the Sacramento River and other tributary watersheds (i.e., reservoir development during the early part of the study period does not preclude using the entire period of record without adjustment).

As shown in Table 2-2, the reservoirs behind Oroville and New Melones dams are two of the largest reservoirs constructed during the period of available inflow measurements. Analyses were made to determine if Oroville Dam and other watershed changes since construction of the dam had a significant impact on Delta inflows from the Sacramento River and Yolo Bypass. Similar analyses were made with regard to San Joaquin River since construction of New Melones Dam.

Table 2-4 summarizes measured Delta inflows for three periods. For the Sacramento watershed, the periods are the pre-Oroville Dam period (1956–1967), the post-Oroville Dam period (1968–2005), and the entire period of record. For the San Joaquin River watershed, the periods are the pre- and post-New Melones Dam periods (1956–1978 and 1979–2005, respectively), and the entire period of record. Since no major storage projects have been developed in the watersheds tributary to the Delta since construction of Oroville and New Melones Dams, the post-dam periods are considered to represent current conditions. As shown in Table 2-4, the average number of days per year with high inflows (>10,000 cfs) from the San Joaquin River is greater during current conditions in the watershed than before New Melones Dam was constructed, and the average number of days per year of low inflows (<10,000 cfs) is less. This situation is contrary to what would be expected if New Melones Dam and reservoir were reducing large flow events. Similarly, Table 2-4 shows more high (>100,000 cfs) and fewer low (<100,000 cfs) total inflows from the Sacramento River watershed since the construction of Oroville Dam.

A statistical analysis was performed to compare the annual peak day Delta inflows for the following stations between two potentially distinct periods:

- Sacramento River + Yolo Bypass: Before 1968 <u>versus</u> after 1968
- San Joaquin River: Before 1979 <u>versus</u> after 1979

The data were tested by Shapiro-Wilk W test and were found to be lognormally distributed. Also, the variances were approximately equal between the two periods. Hence, the parametric *t*-Test, using the log-transformed data, was used to test whether data from the aforementioned periods were different from each other.

The statistical results are presented in Table 2-5. The *p*-values of the *t*-Test were above 0.05, indicating that the annual peak day Delta inflows were not significantly different from each other for the two periods, at the 5 percent significance level (i.e., 95 percent confidence level). Therefore, it is reasonable to combine data from all years together for subsequent analysis.

In summary, it was concluded that the available 50-year period of record data (WYs 1956 through 2005) should be used for the DRMS studies without adjustment for the following reasons:

1. Use of the entire period of available inflow record will reduce any statistical bias caused by the 1987 to 1993 drought years.
2. During major flood events before new reservoir construction, some, if not most flood attenuations were provided by floodplain storage, thereby reducing the impact of new reservoirs on Delta inflows and tending to make the 50-year data set more homogeneous.
3. No major changes in the Sacramento River watershed have occurred since 1968; thus, 38 years of the 50-year period of record represent approximate current watershed conditions.
4. Eleven of the largest 15 annual peak day Delta inflows from the Sacramento River and Yolo Bypass occurred during approximate current watershed conditions.
5. Most of the major reservoirs in the San Joaquin River watershed were completed by 1979, meaning over half of the annual peak day Delta inflows during the 50-year period of record occurred during approximate current watershed conditions.
6. Eight of the largest 15 annual peak day Delta inflows from San Joaquin River occurred during approximate current watershed conditions.
7. Additions to reservoir storage in the San Joaquin River watershed may not have significantly changed inflows into the Delta during major flood events but instead only reduced the amount of floodplain storage that has historically occurred.
8. Analyses of the annual peak day inflow data indicate no statistically significant changes in the data during the period of record.
9. Adjustment of the 50-year inflow record to reflect current watershed conditions would require numerous assumptions regarding reservoir operations and, more important, assumptions regarding downstream levee failures and floodplain storage and would probably incur more error than would result from using the inflow record without adjustment.

2.4.2 Flow Duration Period

Most flood studies are concerned with a maximum flow at a particular location and the associated water-surface elevation, flow velocity, or other hydraulic characteristics. These studies are frequently used for design and generally focus on instantaneous peak flow rates to use in the designs.

In the DRMS studies, we are concerned with hydraulic characteristics throughout the Delta and, for any given location in the Delta, the interaction of differing hydraulic characteristics at other locations in the Delta. These studies are not intended to define a specific event at a specific location for purposes of design. For example, at some locations in the Delta a critical condition at a specific location may be the result of a high (but not instantaneous peak) discharge coupled with a high tide and a high tailwater caused by inflows from other tributaries to the Delta. For these reasons, mean daily TDI was defined as the flow duration period that would best characterize hydraulic conditions and potential flood hazards throughout the Delta. The following list provides specific reasons for selecting mean daily Delta inflows for the analyses.

1. Instantaneous flows at the perimeter of the Delta would be modified as the flows penetrate into and through the Delta and, therefore, would not be representative of concurrent hydraulic characteristics throughout the Delta during a flood event.
2. Analyses of instantaneous peak and mean daily flows available on the Internet (at http://nwis.waterdata.usgs.gov/nj/nwis/discharge) for Sacramento River at Verona and San Joaquin River at Vernalis indicate that, on average for WYs 1956 through 2005, annual instantaneous peak flows are only 1.3 percent higher than annual mean daily flows at the Sacramento station and only 4.3 percent higher at the San Joaquin River station. Thus, mean daily flows are nearly as great as the instantaneous peaks and are sufficiently long to establish their impacts on other areas in the Delta and be coincident with other critical independent factors such as high tides during the day and inflows from other Delta tributaries.
3. The average ratio of 5-day peak inflow into the Delta to the 1-day peak inflow is 89 percent (based on the data shown in Table 2-3 in the column titled “Ratio: Avg. 5-day Peak to Peak Day), thereby indicating that TDIs are not “flashy” and that hydraulic conditions throughout the Delta are relatively constant for extended periods.
4. Annual instantaneous peak flows in San Joaquin River at Vernalis occurred on the same day as the annual instantaneous peak flows in Sacramento River at Verona only two times during the 50 water years from 1956 to 2005 and during these two days it is not likely that the peak inflows occurred concurrently, indicating that instantaneous peak inflows from Delta tributaries are not additive when defining a TDI event and conditions throughout the Delta.
5. It is not likely that peak tide conditions occur concurrently with instantaneous peak inflows.

2.4.3 Flood Season

Another consideration in the DRMS studies is the season of high inflows into the Delta. It is anticipated that repairing damages in the Delta, due to any cause, may be more difficult during the high-inflow season. Also, the possible impacts on Delta exports caused by damages may be different depending on the time of year that the damages occur. Thus, hydrologic characteristics in the Delta during different inflow seasons were considered in the studies.

Figure 2-7 presents average daily Delta inflow versus time of year for inflows during the period of record. As shown on Figure 2-7, high inflows begin near the end of December and last until about the middle of April. Between April 16 and December 15 maximum daily inflows are less than 200,000 cfs, and most of the time maximum daily inflows are less than 100,000 cfs, with the exception of one flood that occurred during October 14–

17, 1962. Based on the above discussion, the “high flow” season for purposes of the Risk Analysis is defined as December 16 to April 15 and the “low flow” season as April 16 to December 15.

3. Flow-Frequency Analyses

3.1 Flow Frequency

Flood frequency as used in the Risk Analysis has a slightly different definition than the definition typically used in flood studies. For purposes of the Risk Analysis, flood frequency in these studies provides a measure of the annual frequency that the total inflow into the Delta will be equaled or exceeded. The frequency associated with the TDI may not correspond to an equivalent frequency on any tributary or specific location in the Delta. Many different inflow patterns into the Delta can produce any selected annual frequency of occurrence, each of which could have its own set of water-surface elevations in the Delta. For example, four storm events in the period of record have peak total daily inflows to the Delta that exceeded the 10-year event. For the largest storm of record, February 1986, the San Joaquin River was not a significant contributor to the storm event, and Cosumnes and Calaveras rivers were. For the second-largest storm, January 1997, both Cosumnes and San Joaquin rivers experienced extreme events, and Calaveras River did not. The third-largest storm occurred only on Sacramento River. Finally, for the fourth-largest storm, March 1983, an extreme event occurred only on San Joaquin River. The Risk Analysis needs to be able to account for all these possible inflow patterns.

The magnitude of the TDI for a hydrologic event of a given frequency can be estimated from a frequency analysis of the measured annual peak inflow events. Table 3-1 summarizes the annual peak TDIs for each of the 50 WYs of record, the 50 high-inflow seasons in the period of record, and the 49 low-inflow seasons in the period of record.

A commonly accepted frequency distribution of hydrologic events is the Log Pearson Type III (LPIII) distribution. This frequency distribution is recommended by the Hydrology Subcommittee of the Interagency Advisory Committee on Water Data published by the USGS (USGS 1982). LPIII uses three distribution parameters: mean, standard deviation, and skew. Annual probabilities were calculated using the data in Table 3-1 to estimate the distribution parameters.

Results of the LPIII analyses are presented in Table 3-2 and Figures 3-1, 3-2, and 3-3 for all water years analyzed (all seasons), high-inflow season, and low-inflow season, respectively. The distributions of seasonal peak daily inflows into the Delta are compared to the all-seasons distribution in Figure 3-4. Table 3-3 presents the estimated parameters for each distribution.

3.2 Probable Maximum Flood Estimates

Figures 3-1, 3-2, and 3-3 and Table 3-2 present estimated flow frequencies for the various confidence limits that were calculated for these studies. As shown by these figures and table, estimated TDI continues to increase as the frequency of exceedance decreases (i.e., the LPIII methodology does not recognize a physical limit on the magnitude of total inflow).

For these studies, an approximation of the Delta PMF inflow was used as the physical upper limit of inflow magnitude. A statistical analysis of the PMF data presented in Table 2-1 was made and is presented on Figure 3-5. As shown by Figure 3-5, the relationship between PMF magnitude and drainage area can be approximated by the following equation.

$$Q = 15{,}223(A)^{-0.4650702} \qquad (3\text{-}1)$$

where:

Q = PMF flow in cfs/square mile

A = Drainage area in square miles

According to the *California Water Plan: Update 2005* (DWR 2005), the total area tributary to the Delta, including the Delta, is about 42,460 square miles. Based on the data presented on Figure 3-5, estimated PMF inflows into the Delta for various confidence limits were calculated and are presented in Table 3-4. The estimated PMF inflows presented in Table 3-4 represent the approximate upper limit of Delta inflows that were used for these studies. The best estimate (50 percent confidence) is approximately 4,500,000 cfs.

The information presented in Tables 3-3 and 3-4 was combined to develop Figures 3-6 and 3-7. These figures provide estimates of Delta inflow for various confidence limits for all water years analyzed (all seasons) and the high-inflow season, respectively, that consider both measured inflows and the physical upper limit of inflows that could be expected.

To combine the PMF estimates with the statistical analysis of measured inflows, it was necessary to extrapolate the PMF data presented in Table 2-1 and Figure 3-5 and to assign a return frequency to the PMF flows. Neither schedule nor budget allowed for a site-specific PMF analysis of the Delta. It is recognized that extrapolation of the PMF data to include a drainage area as large as the Delta may result in an over-estimation of the Delta PMF. However, Delta inflows of interest in the risk analyses are significantly less that the PMF and, therefore, the probabilistic estimates of inflow are not sensitive to the PMF estimate. Also, it is recognized that a PMF is the physical upper limit of inflow that can occur based on meteorological constraints and, therefore, has no statistical frequency of occurrence. For purposes of these analyses, the return frequency of a PMF was assumed to be about 1,000,000 years (frequency of 0.000001). The relationships shown on Figures 3-6 and 3-7 between probabilities of 0.0001 and 0.000001 were visually interpolated. As shown by the plots, estimated Delta inflow is not highly sensitive to the assumed return frequency of the PMF.

3.3 Uncertainty

For the DRMS studies, both the aleatory uncertainty and the epistemic uncertainty of the estimated annual inflow need to be quantified. The aleatory uncertainty is due to the fact that the magnitude of the Delta inflow in a given year are random (cannot be predicted with certainty), even if a large amount of data on Delta historical inflows was available. This uncertainty is captured in the estimated annual frequencies of exceeding different flows using the LPIII model. The epistemic uncertainty is due to the fact that limited data on Delta inflows were available to estimate parameters of the LPIII model. This uncertainty was analyzed by assessing the statistical uncertainty in the parameters of the LPIII model and estimating frequencies of exceeding a given flow at different confidence levels.

To assess the annual frequencies of different flows, the entire range of Delta inflows was divided into smaller ranges (bins), and the annual frequency of occurrence of an annual inflow being in each of the bins was estimated.

The range of Delta inflows was divided into 17 bins where the difference in the natural logarithms of the upper and lower values of a bin is one-seventeenth of the difference in the natural logarithms of the upper and lower values of the total inflow range. The inflow limits for each of the 17 bins are given in Table 3-5. It was assumed that the representative inflow associated with each bin is the flow given by the average of the natural logarithms of the upper and lower inflow values of the bin. The representative inflow for each bin is also presented in Table 3-5.

The annual frequencies of exceeding the lower values of inflow for each of the 17 inflow ranges presented in Table 3-5 were estimated from the plots presented in Figure 3-7 for the 5, 20, 50, 80, and 95 percent confidence limits and are tabulated in Table 3-5. The difference in the annual frequency of exceedance of the upper and lower value of a range of discharge, such as the discharge range of an inflow bin, is the frequency of a discharge within the inflow range (bin) occurring during any given year. (Note that the lower value for $Bin_{(n+1)}$ is the upper value for $Bin_{(n).}$) The estimated frequencies of an annual TDI being in a particular bin is presented in Table 3-5.

The frequencies of an annual TDI being in a particular bin were estimated for confidence limit bins of 0 to 20 percent, 20 to 50 percent, 50 to 80 percent, and 80 to 100 percent for each of the 17 TDI bins from the data presented in Table 3-5. These estimates are summarized in Table 3-6. For example, Table 3-6 shows that for a TDI between 116,362 cfs and 152,553 cfs (bin 6 with a representative inflow of 133,234 cfs), there is a 20 percent probability that the annual frequency is 0.1185, a 30 percent probability that the annual frequency is 0.1195, a 30 percent probability that the annual frequency is 0.1205, and a 20 percent probability that the annual frequency is 0.1215.

The data presented in Table 3-6 can be used to estimate the annual frequency of a discharge for a range of confidence limits. The confidence limits represent the epistemic uncertainty of the estimate, including the uncertainty in the LPIII skew coefficient.

3.4 Results

The frequency analyses of Delta inflows described above resulted in 17 ranges of TDI and the frequency that the annual peak day inflow will be within a particular range. Estimates are provided for five different confidence limits, ranging from 5 percent confidence that the inflow will not be exceeded to 95 percent confidence that the inflow will not be exceeded. The estimated frequencies of an inflow being in each of the 17 ranges are given in Table 3-5 for each of the five confidence limits. Note that the inflow probabilities in Table 3-5 represent a range of inflows equal to the referenced inflow plus and minus 1/34th of the difference in the natural logarithms of the total range of inflows considered in the studies.

The 17 bins resulting from the above analysis represent the range of inflows that are likely to occur in the Delta (i.e., from 0 to 3,000,000 cfs). The Risk Analysis will use the flow from each bin and its associated frequency in the Risk Analysis to cover the range of possible inflows. Because there is uncertainty in the estimate of the annual frequency that a given flow will occur, the Risk Analysis will consider the uncertainty in the annual frequency.

4. Delta Inflow Patterns

4.1 Introduction

Inflow to the Delta comes from several sources, including the Yolo Bypass, Sacramento River, Cosumnes River, Mokelumne River, San Joaquin River, and miscellaneous streams. Miscellaneous streams consist primarily of the Calaveras River. The locations of the flow stations are shown on Figure 2-1. The sum of these sources of inflow is defined as the TDI. Given the variability of flows in the streams making up the TDI, many possible combinations of flows could account for any TDI observed. This section describes a method for defining the different Delta inflow patterns that could account for a selected TDI.

The flow data used in the flow pattern analyses are the same as described in Section 2. This data set consists of 50 years of daily average inflow values from October 1, 1955, through September 30, 2005. However, most of these data represent flows during summer or non-storm winter conditions. Flow patterns that occur during these conditions are controlled to some extent by reservoir releases, are likely different than those during storm events, and are not relevant to the study of the risk of levee failure during a major hydrologic event. A somewhat arbitrary cutoff value of 80,000 cfs was selected to eliminate non-flood inflow patterns, even though flood inflows less than 80,000 cfs are considered in the probability analyses (i.e., we did not want to bias the probabilistic inflow patterns by including small inflows that may be dominated or strongly influenced by reservoir releases). A TDI of 200,000 cfs corresponds to a 50 percent confidence peak annual return period flow of about 3 years.

Table 4-1 summarizes the flow data used in the analyses of inflow patterns. The majority of the inflow into the Delta, approximately 85 percent on average, is from the Sacramento River and Yolo Bypass. The statistics provided in Table 4-1 show that daily average flows in the Sacramento River are not highly variable (the coefficient of variation for daily average flow is only 0.084) and that most of the variability is due to flows in the Yolo Bypass. Flows in these two channels are not independent because the flows originate from the same watershed. Upstream of the City of Sacramento, when the stage in the Sacramento River reaches the crest of the Fremont Weir, flow in the Sacramento River spills into Yolo Bypass. This spill condition occurs at a flow of about 55,000 cfs in the Sacramento River, as measured below the weir. Most of the increase in flow above 55,000 cfs goes over the weir into Yolo Bypass. The Yolo Bypass Working Group et al.

(2001) developed a relationship between flows in the Sacramento River below Fremont Weir and spills over the weir. The relationship indicates that it is only necessary to be able to predict one of the stream flows (Sacramento River or Yolo Bypass), and the other stream flow can be estimated. For this reason, the method presented below is used to predict the sum of flow in the Sacramento River and Yolo Bypass.

4.2 Method

The method for estimating flow in any of the contributing tributaries to the Delta given a specified TDI is to use regression relationships for each contributing inflow. A constraint on the choice of the relationship is that for any TDI (even TDIs beyond what have been observed) the sum of the flows developed from the relationships must add up to the TDI. Therefore, the relationships cannot be independent of each other. The dependence between relationships was maintained by only applying the relationship to that portion of the flow not yet explained by any previously used relationship. The general form of the relationships listed below shows this dependence (there are five inflows if the sum of the Sacramento River and the Yolo Bypass is considered as one inflow).

Q(inflow1) = function (TDI) (4-1a)

Q(inflow2) = function (TDI – inflow1) (4-1b)

Q(inflow3) = function (TDI - inflow1 - inflow2) (4-1c)

Q(inflow4) = function(TDI - inflow1 - inflow2 - inflow3) (4-1d)

Q(inflow5) = TDI - inflow1 - inflow2 - inflow3 - inflow4 (4-1e)

Use of the above relationships ensures that the contributions from each of the tributaries will add to the TDI only if Q(inflow5) is unconstrained (i.e., can take on any value including negative values). To constrain Q(inflow5) to only positive values and to values that are representative of the actual observed values, the regression function needs to be chosen such that:

$$Q_i \leq RI_i \qquad (4\text{-}2)$$

where:

$$RI : R_i = TDI - \sum_{j=1}^{i-1} Q_j$$

$Q_i > 0$ and $Q_0 = 0$

That is, flow in any river [Q(inflow)] has to be less than the remaining inflow (RI).

Using a linear relationship between the logit function and the available inflow as the function in Equations 4-1a through 4-1d guarantees that Equation 4-2 will be satisfied for any value of TDI. This is commonly referred to as logistic regression (Neter and Wasserman 1974). The logit function is defined as:

$$\text{logit}(p) = \ln\left(\frac{p}{1-p}\right) \qquad (4\text{-}3)$$

where p = the fraction of available flow. Using the terms from Equation 4-2,

$$p = (Q_i)/(RI_i) \tag{4-4}$$

and p will always be between 0 and 1. Equation 4-4 could also be written as

$$p = Q\,(\text{river})/RI.$$

Equation 4-5 gives the general form of the logistic regression.

$$Y' = a*Ln(RI) + b \tag{4-5}$$

where Y' = logit(p), is given by Equation 4-3, and "a" and "b" = constants determined from the regression of Equation 4-5 applied to the 50 years of data.

Once constants "a" and "b" are estimated, flow in any river can be calculated from a selected value of TDI using Equations 4-3, 4-4, and 4-5:

$$Q(river) = \frac{RI * \exp(a * \ln(RI) + b)}{1 + \exp(a * \ln(RI) + b)} \tag{4-6}$$

where:

RI is calculated from Equation 4-2.

The order in which the regressions are applied can affect the values of the constants "a" and "b". The best results are obtained when the regressions are applied in order starting from highest inflow (Sacramento River + Yolo Bypass) to the lowest inflow (Mokelumne River). The order of calculating the regressions was: Sacramento + Yolo, followed by the San Joaquin River, miscellaneous flows, the Cosumnes River then the Mokelumne River. The analysis was tried with the above order and with the Cosumnes River and miscellaneous flows reversed. With the Cosumnes and Miscellaneous flows reversed the regression was biased to underestimating the flow rate.

4.3 Results

Table 4-2 lists the results of the logistic regression. The r^2 values for the fit of the logistic regression are near zero except for the Cosumnes River. The low r^2 values result from the large variability in the data. However, even with these small correlations, the equations reproduce the mean values for the flow distributions, as described in Section 4.4.

Figure 4-1 compares the predicted to the measured flows in Sacramento River plus Yolo Bypass. The correlation coefficient for the fit is 0.94.

In addition to the above results, a relationship between the flow in the Sacramento River and Yolo Bypass is needed to separate these two flows from the total. Figure 4-2 shows this relationship.

Figure 4-3 compares the predicted and measured flows for San Joaquin River. The correlation coefficient for the fit is 0.65. The regression equation provides a reasonable fit, though it under-predicts slightly the main body of the data due to the small number of cases where the remaining flow is large and the fraction of flow in San Joaquin River is small (~10 percent of observed values). These events represent cases where a storm occurred on the Cosumnes River but not on the San Joaquin River. Since the method used to generate the flow distributions assumes that the magnitude of the flows can be ranked in a consistent order (i.e., $Q_{sact+yolo} > Q_{sjr} > Q_{misc} > Q_c > Q_{mok}$), those storms that do not follow this pattern increase the variability in the regression model. This source of variability (events not following the pattern shown above) will be captured as described in Section 4.4. Figure 4-4 presents the results for the miscellaneous inflows. The correlation coefficient for the fit is 0.94.

Figure 4-5 shows the results for the Cosumnes River. The correlation coefficient for the fit is 0.96.

4.4 Validation of Method

Table 4-3 compares the mean and median of the observed flows and predicted flows.

The regression relationships reproduce the mean and median of the data well except for the median of Cosumnes River inflows. For most of the rivers, the mean flow is centered within the bulk of the observed flows (e.g., halfway between the 25th and 75th percentiles), whereas for Cosumnes River the mean is almost at the 75th percentile. This implies that the distribution of inflows from Cosumnes River is more skewed than the inflows from other rivers and, therefore, the regression will not reproduce the median values as well.

Figures 4-6 through 4-9 compare measured to predicted flow for Sacramento River plus Yolo Bypass, San Joaquin River, miscellaneous inflows, and Cosumnes River, respectively. All of the figures show a very good fit between the measured and predicted flows except for the San Joaquin River cases in which the flows in other streams exceeded the flow in San Joaquin River. These values are captured as part of the variability analysis described below.

The regression equations do not predict the variability in the inflows since regression equations can only provide a prediction of the mean value. To predict the variability, the root mean square error of the regression was used to estimate random variability around the mean. For any estimate, Equation 4-7 gives the random variability around the mean value:

$$Y_\alpha = Y' \pm k_\alpha \sigma \qquad (4\text{-}7)$$

where:

Y_α = flow parameter with confidence α

Y' = mean estimate of the flow parameter from Equation 4-5

k_α = the confidence coefficient

σ = standard error of the regression

Equation 4-7 applies when the variability around the mean is normally distributed. This is true in logistic space where the regression coefficients were calculated using Equation 4-5. Equation 4-8 is used to transform the results to arithmetic space.

$$Q_{\alpha} = \frac{RI_{\alpha} * \exp(Y_{\alpha})}{1 + \exp(Y_{\alpha})} \tag{4-8}$$

5. Delta Water-Surface Elevations

5.1 General

To calculate the risks of levee failure due to overtopping and/or the effects of high water, estimates must be made of the water-surface elevations throughout the Delta that are associated with various inflow magnitudes, inflow patterns, and downstream tide levels. Water-surface elevations in the Delta were estimated from data on historical water levels measured at selected Delta gauging stations. Water levels, or stages, at the selected gauging stations were then used to interpolate stages at intermediate locations in the Delta. This section discusses the methodology and results of flood stage estimates in the Delta.

5.2 Data Acquisition

5.2.1 Tide Data

Maximum daily tides measured at the San Francisco station (North American Vertical Datum of 1988 [NAVD 88]) were compiled for the period January 1, 1956, through April 15, 2006, approximately the same 50-year record used in the Delta inflow frequency analyses. A plot of the maximum daily tides versus date was made and a linear regression analysis of the data indicated a steady increase in the maximum daily tide during the 50-year record. Consequently, the data were normalized to January 1, 2000, by subtracting the best estimate for each daily measurement and adding the residual to the best estimate for January 1, 2000, thereby providing a consistent record of maximum tide for current (year 2000) conditions. The tide data are available at the following website (NOAA 2005):

http://tidesandcurrents.noaa.gov/station_retrieve.shtml?type=Historic+Tide+Data

Tide measurements during the high Delta inflow season (December 16 through April 15) of each year were extracted from the normalized maximum daily tides at the San Francisco station and a frequency analysis made of the resulting data set. The range of maximum daily tide during the 50 years of normalized high-inflow season tides is 3.88 feet to 9.01 feet. The 6,080 normalized tide measurements were sorted into 22 tide ranges (bins), with each tide range being 0.25 feet. The probability of a maximum daily tide being in a given tide range was calculated. Results of these calculations are presented in Table 5-1 and Figure 5-1.

5.2.2 Stage Data

The CDEC provides information on an extensive hydrologic data collection network, including automatic river stage sensors in the Delta. River stage data are provided primarily from the stations maintained by DWR and USGS (USGS no date). The stage data can be downloaded from the CDEC website (CDEC no date, http://cdec.water.ca.gov/queryCSV.html).

Stage data are provided on an hourly basis since 1984. For some gauging stations, 15-minute stage levels have been recorded for some inflow events since 1995. Figure 5-2 shows the locations of the stage gauging stations selected for use in these studies and presents the period of record for hourly and event data for each station. Gauging stations were selected based on station location and length of available record.

5.3 Data Review and Adjustments

Stage records for the selected gauging stations contained some inconsistent data that are significant enough to have an impact on the results of the analyses. To assist in evaluation of the stage data, plots of daily stage versus time were created for each of the measuring stations. These plots provide a picture of the normal stage range and also show apparent inconsistencies in the data. The data records were evaluated and, when possible, adjusted to eliminate apparent invalid data. The data records were reviewed to adjust or eliminate the following inconsistent data:

- Changes in station datum
- Measured stages exceeding realistic stage elevations
- Missing and known invalid data
- Constant stage measurements
- Invalid recording intervals
- Incomplete daily records

5.3.1 Changes in Station Datum

At some stations, the local station datum was shifted 2 to 3 feet during the period of record. These shifts were not applied to the preceding data record and, in some cases, not mentioned in the metadata for the station. These changes in the station datum are generally obvious in the station record, as illustrated in Figures 5-3 and 5-4.

In discussing changes in station datum with DWR personnel, it was agreed that, in general, these datum changes were made for one of two possible reasons:

- To change the station datum from National Geodetic Vertical Datum of 1929 (NGVD 29) to NAVD 88, which shifts the data range by 2 to 3 feet. The magnitude of these shifts can be calculated using the station latitude and longitude, as provided at the DWR website (http://cdec.water.ca.gov/staMeta.html). For these records, portions of the data record were adjusted to provide a common datum for the entire period of record.
- Datum changes were made at some of the older stations because the mechanical recording device used at the time had difficulty recording negative values. In these instances, the stage records were adjusted upward by 3 feet to avoid recording

negative numbers. Again, the data in the early years were adjusted by 3 feet to provide a common datum for the entire period of record.

5.3.2 Measured Stages Exceeding Realistic Stage Elevations

Some of the records contained values of stage for greater than the normal flood stage for the station. These anomalous data are generally at the beginning of the record or during maintenance of the station and may have been recorded before the equipment was fully calibrated and a datum established. These apparent anomalies were assumed to be invalid and were removed from the data set.

5.3.3 Missing and Known Invalid Data

Some of the available data were recorded as a large negative value such as -9999.99 or as an alpha value such as “m.” These data were either not recorded or known to be incorrect for some reason. These data were eliminated from the data set.

5.3.4 Constant Stage Measurements

Some data records present constant values of stage for extended periods of time. Given that stages are measured to the hundredth of a foot and that stage is impacted by tides, it is expected that recorded stages will fluctuate. Occasionally, stretches of data with the same elevation are repeated for the entire day or multiple days. These data were assumed to be invalid and were not used.

5.3.5 Invalid Recording Intervals

Some of the event (quarter-hour) data are recorded at time intervals not on the quarter hour or on a 1-minute or 5-minute interval. Any data not on the quarter hour or hour were discarded.

5.3.6 Incomplete Daily Records

Each day has 24 stage measurements for hourly data and 96 measurements for quarter-hour event data. Some of the days in the records did not have a complete set of measurements. These studies focused on determining the maximum stage in a given day. To increase the probability that a measurement that is near the highest stage is included in the record, only days with at least 20 hourly measurements or 76 quarter-hour measurements were retained in the data set.

5.4 Conversion of Data to a Known Common Datum

Review and adjustment of the data as discussed in Section 5.3 provides a record for each station that has a single datum for all of the data at each station. However, not all of the selected stations have the same datum, and in some instances it is not known if the datum is NGVD 29, NAVD 88, or some local datum. To compare stations it was necessary to convert all of the station records to the NAVD 88 datum.

The average stage for complete tide cycles (28-day cycle) during August of several water years was calculated for each of the Delta stations. August was selected for these calculations because it is consistently one of the low Delta inflow months. During low inflows, the stages at most stations are primarily a function of tide and not flow, particularly in the central and western part of the Delta.

The average stage at each of the Delta stations was compared to the average stage for the same period at the Golden Gate tide station, which has a known mean sea level (MSL) of 3.39 feet NAVD 88. If the August inflows into the Delta were essentially zero, then the difference between the low flow (August) station average stage and the average August tide elevation at Golden Gate could be used to adjust the datum at each of the Delta stations. However, the August inflows are not zero, and therefore the inflows have some effect on the average measured stage at each station, resulting in a measured stage slightly higher than the August MSL at Golden Gate.

To account for the slightly higher Delta stage levels due to the low August inflows, approximations of the stage increases caused by the inflows were made using data from the more reliable gauging stations in the Delta. The Delta stations used to develop the approximate datum adjustments for inflow are summarized in Table 5-2. All of the stations listed in Table 5-2 have reliable records with a known datum that can be directly converted to NAVD 88. For these stations, the stage increase due to the low inflows can be directly calculated as the difference between the Golden Gate station August MSL and the average NAVD 88 August stages. These differences were then used to further refine the estimates of NAVD 88 mean sea level at the Delta stations. Calculations of stage increases due to the low August inflows are summarized in Table 5-2.

The Mallard Island gauging station is located just west of Pittsburg and east of Suisun Bay. It was used to represent the bottom or exit point from the Delta. The elevation differences shown on Table 5-2 represent a very mild hydraulic gradient between the station location and the Mallard Island station (less than approximately 1×10^{-5} feet per foot gradient). For example, the distance from the Freeport station to the Mallard Island station is approximately 40 miles and the difference in stage between these stations is 2.93, which results in a hydraulic gradient of 0.00001. Gradients for other stations are also shown in Table 5-2.

Table 5-3 summarizes the adjustments made at all of the selected gauging stations in the Delta to convert the data to NAVD 88. Adjustments for August inflows were calculated for those stations listed in Table 5-2. In most cases, no adjustment was required. For the stations in Table 5-3 where August inflow adjustments were calculated, adjustments were estimated based on the known artificial adjustment of the recording device as described in Section 5.3.1 or on the conversion factor from NGVD 29 to NAVD 88 calculated from each station’s latitude and longitude.

5.5 Regression Analyses of Water-Surface Elevations

5.5.1 Matching Station Elevation to Tide and Flow

Once maximum daily stage data were reviewed, invalid records removed, and conversion to NAVD 88 datum estimated for each station, the daily stage data were compiled with the corresponding maximum daily tide data and the mean daily inflow data for each tributary stream. The resulting data set is a daily record of maximum daily stage (NAVD 88), maximum daily tide, and mean daily inflow from each of the six tributary inflows into the Delta.

This study focuses on the threat from high stages that occur during flood events. Most of the inflow data in the data sets represent low-inflow non-flood events. To minimize bias in the statistical analyses of water-surface elevations, the inflow data sets were reduced to only include high-inflow events. Based on review of the data it was judged that only TDI magnitudes greater than 57,000 cfs should be included in the regression analyses.

5.5.2 Regression Analyses of Water-Surface Elevations

Using the data on maximum daily tide, mean daily inflow, and measured adjusted stages at the gauging stations, multiple regression analyses were made for each of the stage-measuring stations. The regression analyses were made to determine best fit coefficients for Equations 5-1 and 5-2. Either Equation 5-1 or 5-2 was used in the regression analyses, depending on the stage measuring station being analyzed. Equation 5-1 was used to estimate stages at the Freeport and Lisbon stations because stages at these stations depend on flow in Sacramento River and Yolo Bypass, respectively, and not the combined flows in Sacramento River and Yolo Bypass. Equation 5-2 was used for the other stage-measuring stations because the measured stage better correlates with the combined Sacramento River and Yolo Bypass flows.

$$WSE_i = aT + b(Q_{Sac})^{b'} + c(Q_{Yolo})^{c'} + d(Q_{SJ})^{d'} + e(Q_{Cos})^{e'} + f(Q_{Mok})^{f'} + g(Q_{misc})^{g'} \qquad (5\text{-}1)$$

$$WSE_i = aT + b(Q_{Sac}+Q_{Yolo})^{b'} + d(Q_{SJ})^{d'} + e(Q_{Cos})^{e'} + f(Q_{Mok})^{f'} + g(Q_{misc})^{g'} \qquad (5\text{-}2)$$

where:

WSE_i = water-surface elevation at station "i"

T = Golden Gate maximum daily tide elevation

Q_{Sac} = Sacramento River inflow

Q_{Yolo} = Yolo Bypass inflow

Q_{SJ} = San Joaquin River inflow

Q_{Cos} = Cosumnes River inflow

Q_{Mok} = Mokelumne River inflow

Q_{misc} = miscellaneous inflow

The theoretically derived weir equation and Manning's Equation for a simple river (e.g., cross-sectional area equal width times depth) indicate that discharge per unit width of flow (q) is proportional to the hydraulic head to the 1.5 power, or, conversely, the hydraulic head is proportional to discharge to the 0.67 power (Streeter and Wylie 1979). Thus, the b' through g' exponents in Equations 5-1 and 5-2 were set equal to 0.67. Coefficients "a" through "g" are determined from the regression analyses.

Each component of Equations 5-1 and 5-2 represents the contribution to the expected stage of tide and flow from each inflow source.

In the regression analyses, a condition was imposed on the “a” through “g” coefficients to restrict these coefficients to positive values. Negative values for these coefficients would indicate a decrease in stage for an increase in flow, which is not realistic.

Regression analyses were performed for the 15 stage-measuring stations listed in Table 5-3. The multiple linear regression analyses were solved in two steps. In the first regression, the average absolute error was minimized. In the second regression, the average error was minimized. The absolute average error ranged from 0.17 feet to 0.92 feet.

The coefficients “a” through “g” derived from the regression analyses are presented in Table 5-4. The resulting average absolute error and maximum error were determined and are also presented in Table 5-4.

5.6 Evaluation of Flood Stage Equations

At each station the measured water-surface elevation was compared to the water-surface elevation calculated using the coefficients listed in Table 5-4. Figure 5-5 compares the calculated stage with the measured stage at Venice Island for the period January 1998 to July 1998. Similar comparisons for the stations listed in Tables 5-2, 5-3, and 5-4 are provided in Appendix A. Also, the observed annual peak at each station is compared to the predicted annual peak for stations with four or more years of data. For most stations, the root mean square error is equal to 0.34 feet or less. Only two stations, Benson’s Ferry and Liberty Island, have root mean square errors that are greater than 1 foot.

5.7 Interpolation of Stages at Intermediate Locations

Given the coefficients “a” through “g”, a stage elevation can be predicted at each of the selected stage-measuring stations (primary stations) for any inflow pattern and tide condition. Stage estimates are also needed at locations where measured data are not available. Critical locations were selected (e.g., stream junctions) (secondary stations), and the stage at these locations was estimated by linear interpolation of the distances along the primary Delta channel flow path between the primary locations that passed through the secondary station.

5.8 Assumptions and Limitations

These analyses assume a channel system within the Delta that is regular and that behaves consistently over the period since 1984, when stage data first became available. At least two artificial (human-made) conditions exist in the Delta waterways that may account for some of the error found in the equations.

The weir near the Lisbon station can be operated to release flows at different stage elevations on the Sacramento River. The relatively larger error for this station may partly result from water releases made at different stage elevations over the past 22 years. For example, operators may choose to begin to release water at a lower-than-usual stage to minimize the danger to urban areas from higher flows expected in the near future. These operational issues have not been explored in these analyses.

The Delta Cross Channel near Walnut Grove may also be operated in a manner that could impact the accuracy and consistency of the equations developed in this memorandum, though the gates at this facility are generally closed during the high inflow season. For the purposes of these analyses, the impacts of operations at the Delta Cross Channel do not significantly change the results of these studies.

Finally, these analyses assume that failures in the levee system for any given inflow condition will not significantly reduce the downstream stage along the channels. This may or may not be the case depending on the magnitude of the flood inflow, when the breach occurs, and the volume of the breached island. For those cases where a levee breach occurs before the peak water-surface elevation and lowers downstream water-surface elevations, the results of these studies will over-predict the water-surface elevation.

It should be noted that the equations for predicting stage were derived from actual measurements of inflows, tide, and stage. When the equations are used to predict stages during hydrologic events that are more severe than those included in the data set, they may, in many cases, predict stages that are higher than the levee crests. To the extent that levee overtopping (and possible levee failure) will convert the flooded island(s) into an effective conveyance channel through the Delta, the predictor equations would overestimate stages. The equations are only intended to predict how high the flood flows are on the levee banks and if the levees are overtopped. They are not intended to predict stages in excess of the levee crests.

6. Future Hydraulic Risks

6.1 Data

Two different climate models and two different climate change scenarios were used to estimate daily flows in 23 study area streams; the two models and two scenarios provided four different 150-year records of daily flows. The climate models and climate change scenarios are described in *Technical Memorandum: Delta Risk Management Strategy (DRMS) Phase 1, Topical Area – Climate Change* (DWR 2007a) and *Technical Memorandum: Delta Risk Management Strategy (DRMS) Phase 1, Topical Area – Water Analysis Module (WAM)* (DWR 2007b, Appendix F). The results are provided as a Special Report on Emissions Scenarios (SRES). The characteristics of the four different climate change scenarios are summarized below:

Scenario Name	CO_2 Increase	Global Climate Model Used
SRESa2 – gfdl	CO_2 emissions continue to accelerate	National Oceanic and Atmospheric Administration (NOAA) Geophysical Fluid Dynamics Laboratory (gfdl)
SRESb1 – gfdl	The rate of emissions growth moderates and the emission rates themselves eventually decrease	National Oceanic and Atmospheric Administration (NOAA) Geophysical Fluid Dynamics Laboratory (gfdl)

Scenario Name	CO_2 Increase	Global Climate Model Used
SRESa2 – ncar	CO_2 emissions continue to accelerate	Parallel Climate Model (pcm), by the National Center for Atmospheric Research (ncar)
SRESb1 – ncar	The rate of emissions growth moderates and the emission rates themselves eventually decrease	Parallel Climate Model (pcm), by the National Center for Atmospheric Research (ncar)

A key assumption in using the synthetic runoff records generated by the four climate change scenarios to estimate probabilities of future Delta inflows is:

> The future change in frequency of a given current return frequency event that occurs in the watershed will produce the same change in frequency for the Delta inflow of the same current return frequency.

In other words, the shift in the frequency curve for Delta inflow will be the same as the shift in the frequency curves for watershed runoff. For example, if the current 100-year watershed runoff event, as determined from analyses of the synthetic records for the 23 study area streams, has a 50-year return frequency in year 2100, then the current 100-year Delta inflow event will have a 50-year return frequency in year 2100. This assumption may not be accurate if daily runoff values are used because estimated inflows into the Delta in some streams during some storm events may be significantly attenuated by reservoirs located between the stream flow locations and the Delta. This potential inaccuracy can be reduced by defining the watershed event as the average runoff in the streams that occurs over a period of several days, thereby attenuating and smoothing the flows in a manner similar to that of a reservoir.

For purposes of estimating future probabilities of Delta inflows, the annual watershed runoff event was defined as the largest annual value of the 7-day sum of total daily runoff amounts in the 23 streams. In other words, the estimated daily runoff volumes in each of the 23 streams were added together to give 150 years of daily sums. A 7-day running total was calculated for this record, and the largest value in each year was selected as the annual event.

Annual watershed runoff events, calculated as described in the preceding paragraph, were determined for each of the four climate change scenarios and evaluated to identify future changes in hydrologic events and select periods of the records to be used in estimating Delta inflow events. Figure 6-1 presents the cumulative sum of annual peak runoff events in the watershed for each of the four climate change scenarios. As shown in Figure 6-1, the trend in cumulative peak runoff with time is linear and essentially the same for the four scenarios for the period 1950 to about 2010. After approximately year 2010, cumulative peak runoffs for the four scenarios begin to deviate from the earlier linear relationship. Thus, no noticeable climate change impacts occur before year 2010, and the 1951 to 2000 period of record can be used to represent current hydrologic conditions. Therefore, the period 2026 to 2075 is used to estimate hydrologic conditions in the year 2050, and the period 2051 to 2100 is used to estimate hydrologic conditions in the year 2075.

6.2 Frequency Analyses

Having defined and estimated watershed runoff events as described in Section 6.1, the following steps were used to estimate Delta inflow under future climatic conditions in years 2050 and 2100.

6.2.1 Step 1: Determine Data Skew for Frequency Analyses

Frequency distributions for each of the four synthetic records were analyzed in 50-year segments. Fifty data points of annual peak runoff were not sufficient to define the data skew coefficient, resulting in varying skew coefficients for each 50-year segment of record and large variations in the analyses results. Thus, it was decided to use the skew coefficient associated with the 150-year record. In the LPIII distribution, the skew used is that of the natural logarithm of the annual peaks. These skew coefficients were calculated for each of the four future climate scenarios as follows:

Scenarios (As described in DWR 2007a)	150-Year Skew of Natural Logarithm of Annual Peak
Sresa2-gfdl	-0.263432
Sresa2-ncar	-0.108138
Sresb1-gfdl	-0.140541
Sresb1-ncar	-0.246774

6.2.2 Step 2: Calculated Log Pearson Type III Frequency Distributions

For each of the future climate scenarios and their associated skew coefficients, LPIII frequency distributions were fitted to the data for the periods 1951 to 2000, 2001 to 2050, 2026 to 2075, and 2051 to 2100 in each 150-year record. The period 1951 to 2000 was used to represent current hydrologic conditions. The period 2001 to 2050 was used to represent hydrologic conditions in 2025, the period 2026 to 2075 to represent hydrologic conditions in 2050, and the period 2051 to 2100 to represent hydrologic conditions in 2075. For each probability distribution analysis, 5 percent, 20 percent, 50 percent, 80 percent, and 95 percent confidence limits were calculated. Figure 6-2 illustrates the results of the analysis of the 50 percent confidence limit calculation using future climate scenario Sresa2-gfdl.

6.2.3 Step 3: Estimate the Probability of Year 2000 Runoff Values Occurring in Future Years

Probabilities of exceedance for selected peak annual watershed runoff amounts were estimated for present and future climate conditions using the curves developed in Step 2. Table 6-1 illustrates estimated probabilities for climate scenario Sresa2-gfdl with a 50 percent confidence limit, as derived from the plots in Figure 6-2. The scales presented in Figure 6-2 had to be greatly expanded to estimate the probabilities presented in Table 6-1. The estimated probabilities of exceedance for years 2000, 2025, 2050, and 2075 were extrapolated to produce estimates of the probabilities of exceedance of the selected runoff magnitudes in year 2100. These estimates are also presented in Table 6-1. Note that the discharges presented in Table 6-1 represent annual peaks of the 7-day total runoff in the 23 watershed streams.

6.2.4 Step 4: Convert Watershed Runoff Events to Delta Inflow Events

As previously discussed, it is assumed the shift in the frequency distribution that occurs in the watershed under future conditions will produce the same shift in the frequency distribution of Delta inflows. This adjustment results in the Delta inflow magnitudes and probabilities of exceedance for years 2000, 2050, and 2100 that are shown in Table 6-2 for the Sresa2-gfdl climate change scenario. The estimates presented in Table 6-2 were also developed for the other three climate change scenarios.

6.2.5 Step 5: Select Ranges of Delta Inflows (Bins) for Analyses

Examination of the data in Table 6-2 and similar data for the other three climate change scenarios indicates that the infrequent annual peak Delta inflows in the future will be larger than during current climate conditions. To include all potential inflow events that could significantly contribute to Delta risks, the range of inflows selected for analysis of future conditions was from a low of 200,000 cfs to a high of 5,000,000 cfs. As shown by the data in Table 6-2, this range includes year 2100 inflows from approximately a 450-year event at the 95 percent confidence limit to approximately a 5-year event at the 5 percent confidence limit.

The total range of inflows (200,000 to 5,000,000 cfs) was divided into 15 bins. As with the analyses of current conditions discussed in Section 3, the difference in the natural logarithm of the upper and lower discharge limits of each bin is equal to one-fifteenth of the difference in the upper and lower limits of the total range. The range of inflows associated with each bin and the designated bin discharge are presented in Table 6-3. The designated bin value is the mean of the upper and lower inflow for each bin.

6.2.6 Step 6: Estimate Probabilities of Inflows Being in a Designated Range (Bin)

As with the frequency estimates of current Delta inflows discussed in Section 3, a limit was set on the maximum possible inflow under future conditions. For the analyses of current conditions, the maximum was set at a value comparable to the PMF. It was assumed that the current condition maximums presented in Section 3 would increase by 10 percent for year 2050 conditions and increase by 20 percent for year 2100 conditions. As discussed in Section 3, the sensitivity of the study results to the assumed increases in PMF is small.

The data provided in Table 6-2 and similar data for the other three climate scenarios were combined with the bin data in Table 6-3, and the increased upper limits of Delta inflow were used to prepare plots of inflow versus probability of exceedance. An example of the plots is presented in Figure 6-3 for year 2100 conditions and climate scenario Sresa2-gfdl.

Using the plots similar to Figure 6-3, probabilities of exceedance were determined for the upper and lower discharge limits of each of the 15 bins for each of the study years (2000, 2050, and 2100) and each of the four climate change scenarios. The results of these estimates are illustrated in Table 6-4 for climate change scenario Sresa2-gfdl.

The difference in the probabilities of exceedance of the upper and lower inflow values of each bin is the probability that the inflow will be in the inflow range of the bin. The probabilities of inflows being in a designated bin range were calculated for each of the 15 bins for each of the study years (2000, 2050, and 2100) and each of the four climate change scenarios. The results of these estimates are illustrated in Table 6-5 for climate change scenario Sresa2-gfdl.

The data presented in Table 6-5 and similar data for the other three climate scenarios were smoothed by plotting the data and calculating equations that best fit the data. Figure 6-4 illustrates the relationships between mean bin inflow and the annual probability of a hydrologic event being in the bin inflow range for year 2100 and climate change scenario Sresa2-gfdl.

6.3 Results of Frequency Analyses for Future Climate Conditions

Mean inflow values and the range of inflows for each bin used in the analyses of future climate conditions are summarized in Table 6-3. Equations giving the probabilities of a future hydrologic event being in a particular bin range are summarized in Table 6-6 for years 2050 and 2100 and confidence limits of 95, 80, 50, 20, and 5 percent.

The following example, which uses the Sresa2-gfdl climate change scenario, is presented to clarify the assumptions and methodology for estimating future Delta inflow magnitudes, frequencies, and confidence limits. As shown on Figure 6-2, the 23-stream, 7-day total runoff in the watershed that has a present day (1951–2000 curve) 0.01 frequency of exceedance at the 50 percent confidence limit is about 6,300,000 cfs-days. In the year 2050 (2026–2075 curve), the 6,300,000 cfs-days runoff will have a frequency of exceedance at the 50 percent confidence limit of about 0.022. As shown on Figure 6-3, a present day TDI of about 1,500,000 cfs has a 0.01 frequency of exceedance at the 50 percent confidence limit. For the year 2050, this value of TDI (1,500,000 cfs) was assigned a frequency of exceedance at the 50 percent confidence limit of 0.022. TDI values for other frequency exceedances, confidence limits, and climate change scenarios were estimated in the same manner to obtain the relationships presented in Table 6-6.

6.4 Future Delta Inflow Patterns

Analyses of the synthetic runoff data for climate change scenario Sresa2-gfdl were made to determine if the inflow patterns discussed in Section 4 would be different in future years. For each of the 23 streams included in the record, the 7-day runoff amounts that contribute to the 43 largest annual watershed runoff events were extracted from the data set. The 43 largest annual runoff events consist of 16 events during the period 1951 through 2000, 13 events during the period 2001 through 2050, and 14 events during the period 2051 through 2100. For each of the 50-year periods, the average percent contributions to the runoff events were calculated for each of the 23 streams. Results of these calculations are presented in Table 6-7.

Examination of the data in Table 6-7 shows no significant time-dependent trends, either on an individual stream basis or on a regional basis. Based on these analyses, it was decided that the same Delta inflow patterns would be used for years 2050 and 2100 as were developed in Section 4 for current conditions.

6.5 Future Delta Water-Surface Elevations

Water-surface elevations in the Delta will change in the future due to rising sea levels. The increases in sea level cannot simply be added to the water-surface elevations estimated as described in Section 5; the sea-level rise will change the hydraulic characteristics of flows through the Delta and its impact should decrease the farther inland a location is and the larger the storm event. A simple method to approximate changes in water-surface elevations in the Delta due to sea-level rise was developed and is described in the following paragraphs.

A rise in sea level increases the tailwater that inflows must overcome to pass through the Delta and enter San Francisco Bay. For any given inflow magnitude and pattern flow, depths in the Delta channels will be larger, thereby reducing flow velocities and hydraulic head losses. The reduction in hydraulic head loss must be accounted for in estimating water-surface elevations under future increased sea-level conditions. The following assumptions were made in analyzing impacts of sea-level rise on water-surface elevations in the Delta:

1. Manning’s Equation can be used to describe the flow in the Delta channels during storm events.
2. The channels are much wider than they are deep; therefore, the hydraulic radius can be approximated as the channel depth.
3. The slope of the channel can be approximated as the water-surface slope between the station of interest and the next downstream station.
4. The water-surface elevation at any station can be approximated using the relationships developed in Section 5.

Using the above assumptions, the sea-level rise at any location in the Delta can be estimated using Equation 6-1.

$$\left(\frac{h_B}{h_B + d_B}\right)^{5/3} = 1 + \frac{d_B - d_A}{f_B(Q_i) - f_A(Q_i)} \tag{6-1}$$

where:

h_B = water depth at location of interest

d_B = sea-level rise at point of interest

d_A = known sea-level rise at downstream point

$f_B(Q_i)$ = water-surface elevation at point of interest calculated from relationships in Section 5

$f_A(Q_i)$ = water-surface elevation at point downstream calculated from relationships in Section 5

Equation 6-1 is applied starting from the farthest downstream point (e.g., the Mallard Island station) and moving upstream.

7. Summary and Verification

The following example calculation is provided to summarize the calculation procedures developed to estimate the frequencies of water-surface elevations throughout the Delta. The calculated frequencies and water-surface elevations are compared to the estimated frequencies of measured water-surface elevation to validate the accuracy of the DRMS methods. The example calculations were made using a simple spreadsheet model and, to limit memory space needed for the spreadsheet model, the water-surface elevation calculations were limited to only one station in the Delta, the station at Venice Island (Station VNI). The VNI gauging station has a relatively long period of water-surface elevation measurements. To further limit calculation requirements, the epistemic uncertainties associated tide levels and with the equations for estimating water-surface elevations (equations 5-1 and 5-2) were not included in the example calculations. It was assumed that any epistemic uncertainties associated with tide levels could be neglected because of the large number of tide measurements used to establish probabilities of tide levels.

Variables that are included in the example calculations are:

1. The frequency of the TDI being in each of the 17 inflow ranges (bins) presented in Table 3-5 for each of the four confidence levels presented in Table 3-6.
2. Frequencies for five levels of confidence (20 percent, 40 percent, 60 percent, 80 percent, and 100 percent confidence of non-exceedance) for the magnitude of inflow from each of the four major Delta inflow tributaries (Mokelumne River inflow is used to make up the difference between TDI and the sum of inflow from the four major tributaries).
3. Probabilities of 22 tide ranges (bins) varying from the minimum (3.75 feet) to maximum (9.25 feet) tide observed during the past 50 years (tide levels were adjusted to reflect year 2000 conditions—see Section 5.2.1).

Even with the above limitations, a significant number of calculations were necessary for the example calculation. The four major Delta tributaries, each with five confidence limit probabilities, were combined with the 17 TDI ranges, each with four confidence limit probabilities, and the 22 probabilities of tide levels, resulting in 935,000 different combinations of Delta tide, TDI, and inflow pattern (5 x 5 x 5 x 5 x 17 x 4 x 22 = 935,000).

Each of the 935,000 combinations of tide, TDI, and inflow pattern will have a probability of occurrence and will result in a different calculated water-surface elevation at each of the 15 primary Delta water-surface elevation stations shown on Figure 5-2. For example, a tide between 4.75 and 5.00 feet (tide bin #5) when coupled with the 20 percent confidence probability of a TDI between 88,757 and 116,362 cfs (TDI bin #5) that is composed of flows in all four of the major tributaries that have a 20 percent probability of non-exceedance will have a probability of 0.00000764, which is equal to 0.0444 (tide probability, Table 5-1) times 0.1075 (TDI probability, Table 3-6, 20 percent confidence probability) times 0.2^4 (20 percent probability of non-exceedance in each of the four major Delta tributaries).

For the example calculation, the water-surface at the VNI station was calculated for all 935,000 combinations of tides, TDIs, and inflow patterns discussed above. It should be stressed that even though this example calculation estimates the annual frequencies of water-surface elevations at a single location, the intent of the methodology is to calculate concurrent water-surface elevations throughout the Delta to estimate the Delta-wide risks of flooding.

The annual frequencies of water-surface elevations at the VNI gauging station, calculated from probabilities of tides, TDIs, and flow patterns, are compared to the annual frequencies of water-surface elevations estimated from Weibull plotting positions of annual peak water-surface elevations measured at the gauging station. Table 7-1 summarizes measured water-surface elevations at the VNI station as reported by the U.S. Army Corps of Engineers (USACE 1992) and CDEC (no date). The Weibull plotting position, which is an estimate of the return frequency of an event, is defined as the number of years of record plus 1 (n + 1) divided by the rank (m) of the event, where a rank of m=1 is the largest annual event and a rank of m=n is the smallest annual event. Figure 7-1 compares the two estimates of water-surface elevation frequencies and, as shown by Figure 7-1, the DRMS model estimates return frequencies that are nearly identical to the frequencies given by the Weibull plotting positions of the measured data.

As shown by Figure 7-1, the 100-year water-surface elevation at the VNI gauging station is about 11.4 feet NAVD This is about 1 foot higher than reported in the U.S. Army Corps of Engineers Special Study of the Delta (USACE 1992).

8. References

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Tables

Table 2-1: PMF Estimates

	PMF Location	Area mi.2	PMF Estimates, cfs/mi.^{2}
	PMF Estimates By USBR		
1	Little Pinto Basin nr. Old Irontown, UT	0.30	9,967
2	Boney Branch nr. Rockport, MO	0.76	15,658
3	Dark Gulch nr. Glen Haven, CO	1.00	12,900
4	Headgate Draw nr. Buffalo, WY	1.10	10,091
5	Big Creek nr. Waynesville, NC	1.32	19,394
6	No. Fork Tributary, Big Thompson river nr. Glen Haven, CO	1.38	11,667
7	Stratton Creek nr. Washta, IA	1.90	6,947
8	Tributary to Dry Walnut Creek nr. Pawnee Rock, KS	2.28	6,316
9	Tributary to Kinneman Creek, ND	2.45	6,122
10	Travertine Creek nr. Sulphur, OK	3.00	8,300
11	South Fork Pine Canyon nr. Waterville, WA	4.50	6,222
12	Caney Creek nr. Eureka Springs, MS	4.90	8,204
13	Lane Canyon nr. Echo, OR	5.00	6,240
14	Brush Creek at 63d Street, Kansas City, MO	5.90	7,525
15	Round Grove Creek at Raytown Road Kansas City, MO	5.90	8,915
16	El Rancho Arroyo nr. Pajoaque, NM	6.70	7,493
17	Wayman Creek nr. Garber, IA	6.98	4,742
18	Molly Fork nr. Guernsey, WY	7.00	5,471
19	Boone Fork nr. Wilhurst, KY	7.40	6,446
20	Cass Draw nr. Carlsbad, NM	9.30	6,022
21	Nederlo Creek at Gays Mills, WI	9.46	3,953
22	Tig Trout Creek nr. Pickwick, MN	9.90	4,071
23	Trumansburg Creek nr. Trumansburg, NY	11.5	6,704
24	Meyers Canyon nr. Mitchell, OR	12.7	5,134
25	Brush Creek at Main Street, Kansas City, KS	14.8	6,128
26	Blieders Creek nr. New Braunfels, TX	15.0	5,413
27	Spring Creek nr. Fredericksburg, TX	15.2	6,086
28	Indian Wells Canyon nr. Inyokern, CA	16.6	4,747
29	Bronco Creek nr. Wickieup, AZ	19.0	5,195
30	Eldorado Canyon, NV	22.8	4,855
31	Bull Run nr. Catharpin, VA	25.8	4,217
32	Balm Creek nr. Heppner, OR	27.0	3,363
33	Percha Creek nr. Hillsboro, NM	35.4	3,831
34	Sergeant Major Creek nr. Cheyenne, OK	36.0	3,075
35	North Fork Hubbard Creek nr. Albany, TX	39.3	4,115
36	Otter Creek nr. Hanover, ND	42.9	1,944
37	North Fork Wahoo Creek nr. Weston, NE	43.7	2,023
38	Jimmy Camp Creek nr. Fountain, CO	54.0	3,537
39	Rapid Creek nr. Rapid City, SD	54.0	2,033
40	Wilson Creek nr. Adako, NC	66.0	2,848
41	North Prong Medina River nr. Medina, TX	67.5	2,996
42	Wewoka Creek nr. Lima, OK	75.0	2,276
43	Mailtrail Draw nr. Loma Alta, TX	75.3	3,491
44	East Plum Creek nr. Castle Rick, CO	108	3,043
45	Whites Creek nr. Spring City, TN	108	3,407
46	Wild Horse lCreek nr. Enid, OK	116	1,922
47	Arbuckle Dam nr. Sulphur, OK	126	3,032
48	Seco Creek nr. D'Hanis, TX	142	2,462
49	Little Nemaha River nr. Syracuse, NE	218	1,273
50	Middle Fork, Little Red River nr. Shirley, AR	302	1,054
51	Plum Creek nr. Louviers, CO	308	1,782
52	Two Medicine River nr. Browning, MT	317	626
53	Flint River nr. Chase, AL	342	761
54	Tye River nr. Norwood, VA	360	1,229
55	West Nueces River nr. Kickapoo Springs, TX	402	1,719
56	Santa Ana River nr. Riverside Narrows, CA	720	613
57	Bijou Creek nr. Wiggins, CO	1,380	529
58	So. Fork Republican River nr. Hale, CO	1,612	381
59	Neosho river nr. Strawn, KS	2,933	288
60	Pecos River nr. Comstock, TX	3,000	533
61	Eel River nr. Scotia, CA	3,113	319
	PMF Estimates From the Internet		
1	Trinity Dam, CA	692	490
2	New Molones Dam, CA	904	164
3	Friant Dam, CA	1,650	348
4	Folsom Dam, CA	1,875	363
5	Shasta Dam, CA	6,665	93

Table 2-2: Partial List of Major Dams and Reservoirs in Watersheds Tributary to San Francisco Bay Delta

Dam Name	ID	Watercourse	Tributary Drainage Area, Mi^2	Tributary of:	Reservoir	Year Original Construction Completed	Reservoir Capacity (acre-feet)
San Luis		San Luis Creek		Mendota Canal	San Luis	1967	2,041,000
O'Neill		San Luis Creek		Mendota Canal	O'Neill Forebay	1967	
Shasta	**SHA**	Sacramento River	6,665	Sacramento River	Shasta Lake	1945	4,552,000
Oroville	**ORO**	Feather River	3,607	Sacramento River	Lake Oroville	1968	3,537,580
Monticello	**BER**	Putah Creek	576	Sacramento River	Lake Berryessa	1957	1,602,000
Almanor	**ALM**	N Fork Feather River	503	Sacramento River	Lake Almanor	1964	1,308,000
Cache Creek	**CLA**	Cache Creek	514	Sacramento River	Clear Lake	1914	1,115,000
Folsom	**FOL**	American River	1,885	Sacramento River	Folsom Lake	1956	1,010,000
New Bullards Bar	**BUL**	Yuba River	481	Sacramento River	New Bullards Bar	1969	960,000
Indian Valley	**INV**	N Fork Cache Creek	122	Sacramento River	Indian Valley	1976	300,600
Whiskeytown	**WHI**	Clear Creek	202	Sacramento River	Whiskeytown Lake	1963	241,100
Black Butte Dam	**BLB**	Stony Creek	741	Sacramento River	Black Butte Lake	1963	143,700
East Park		Little Stony Creek		Sacramento River	East Park	1910	50,889
Stony Gorge		Stony Creek		Sacramento River	Stony Gorge	1928	50,000
Englebright		Yuba River		Sacramento River		1941	45,000
Sly Park		Sly Park Creek		Sacramento River	Jenkinson Lake	1955	41,000
Keswick		Sacramento River		Sacramento River	Keswick	1950	23,800
Sugar Pine		N Shirttail Creek		Sacramento River	Sugar Pine	1981	6,921
Spring Creek Debris Dam	**SPC**	Spring Creek		Sacramento River	Spring Creek	1963	5,870
Daguerre Point		Yuba River		Sacramento River		1910	
Capay Diversion Dam		Cache Creek		Sacramento River		1914	
Red Bluff (Diversion)		Sacramento River		Sacramento River	Lake Red Bluff	1964	
New Melones	**NML**	Stanislaus River	900	San Joaquin River	New Melones	1979	2,400,000
New Don Pedro	**DNP**	Tuolumne River	1,533	San Joaquin River	New Don Pedro	1923, 1971	2,030,000
New Exchequer	**EXC**	Merced River	1,040	San Joaquin River	Lake McClure	1926, 1968	1,026,000
Buchanan	**BUC**	Chowchilla River	235	San Joaquin River	Eastman Lake	1975	150,000
Hidden	**HID**	Fresno River	234	San Joaquin River	Hensley Lake	1975	90,000
Friant	**MIL**	San Joaquin River	1,675	San Joaquin River	Millerton Lake	1942	520,000
Tulloch		Stanislaus River		San Joaquin River	Tulloch	1957	68,000
Los Banos (Detention)		Los Banos Creek		San Joaquin River	Los Banos	1965	
Little Panoche (Detention)		Little Panoche Creek		San Joaquin River	Little Panoche	1966	
Martinez		off-stream storage			Martinez	1947	
Contra Loma		off-stream storage			Contra Loma	1967	
Comanche	**CMN**	Mokelumne River		San Joaquin River	Comanche	1963	431,000
Pardee	**PAR**	Mokelumne River		San Joaquin River	Pardee	1929	210,000
New Hogan	**NHG**	Calaveras River		San Joaquin River	New Hogan	1931, 1964	325,000

Table 2-3: Annual Peak Day Delta Inflows of Record (WY 1956 Through 2005)

Water Year	Date, WY Peak Inflow Day	Peak Day Sacramento River, cfs	Peak Day Yolo Bypass, cfs	Peak Day Cosumnes River, cfs	Peak Day Mokelumne River, cfs	Peak Day Misc. Streams, cfs	Peak Day San Joaquin River, cfs	Peak Day Total Inflow, cfs	Average 5-day Peak Inflow, cfs	Ratio: Avg. 5-day Peak to Peak Day	5-Day Inflow Vol. Up Through Peak Day, ac-ft	5-Day Inflow Vol. Up Through Peak Day, ac-ft
1986	February 20, 1986	113,000	499,301	15,600	4,490	14,981	13,900	661,272	551,714	0.83	4,501,390.41	1,571,520
1997	January 3, 1997	113,000	395,140	19,200	4,250	5,699	24,700	561,989	493,338	0.88	3,641,896.86	959,768
1965	December 25, 1964	98,600	343,265	11,500	150	2,607	14,000	470,122	382,948	0.81	2,673,209.26	2,281,874
1983	March 4, 1983	83,100	274,300	6,490	3,350	13,173	41,800	422,213	381,167	0.90	3,127,846.61	797,068
1995	March 13, 1995	96,100	266,562	6,340	2,440	1,635	14,100	387,177	336,016	0.87	2,229,883.64	741,241
1970	January 25, 1970	93,000	255,600	5,970	4,330	3,821	21,200	383,921	362,105	0.94	3,304,076.03	455,516
1956	December 23, 1955	90,200	249,600	34,100	2,180	4,032	3,210	383,322	276,247	0.72	1,571,520.00	1,131,743
1984	December 28, 1983	92,700	221,988	7,010	3,840	7,484	18,600	351,622	305,986	0.87	2,345,680.66	1,190,319
1963	February 2, 1963	94,400	230,107	17,300	3,260	1,962	3,830	350,859	202,799	0.58	1,190,318.68	399,078
1980	February 22, 1980	94,100	202,145	9,190	1,730	11,543	20,300	339,008	303,426	0.90	2,285,049.92	2,673,209
1998	February 8, 1998	86,800	193,521	6,130	2,930	7,331	26,300	323,012	305,585	0.95	2,823,322.31	596,854
1969	January 27, 1969	87,000	134,770	10,600	4,160	5,480	41,700	283,710	259,060	0.91	2,608,720.66	1,807,500
1958	February 26, 1958	85,500	174,510	6,140	1,650	3,276	7,750	278,826	245,784	0.88	2,281,874.38	798,413
1974	January 20, 1974	94,200	165,350	4,360	2,250	1,642	8,290	276,092	251,157	0.91	1,960,831.74	2,608,721
1982	February 17, 1982	98,000	103,742	11,700	3,030	14,203	7,720	238,395	175,241	0.74	1,041,399.67	3,304,076
1967	February 1, 1967	90,100	132,590	6,060	93	918	8,070	237,831	211,254	0.89	1,807,499.50	923,631
1973	January 19, 1973	92,700	112,559	6,790	1,910	2,472	6,370	222,801	196,152	0.88	1,728,842.98	337,839
1996	February 23, 1996	86,800	93,818	2,900	2,840	5,262	15,400	207,020	193,127	0.93	1,647,205.29	1,728,843
2004	February 28, 2004	73,800	105,288	1,500	326	1,050	4,220	186,184	177,486	0.95	1,594,216.86	1,960,832
1978	January 18, 1978	75,000	85,024	5,100	114	5,062	4,150	174,450	158,930	0.91	1,310,340.50	1,126,078
2000	February 28, 2000	81,700	63,375	5,010	2,010	3,071	13,600	168,766	156,851	0.93	1,446,424.46	325,369
1962	February 16, 1962	70,100	68,679	7,520	547	2,826	7,820	157,492	137,722	0.87	1,131,742.81	122,450
1993	March 28, 1993	82,300	53,026	3,280	431	662	3,950	143,649	136,829	0.95	1,300,621.49	1,310,340
1960	February 10, 1960	69,100	67,482	3,280	156	712	2,130	142,860	108,434	0.76	741,240.99	838,080
1999	February 11, 1999	85,400	31,150	3,630	2,770	6,568	11,900	141,418	124,608	0.88	991,787.11	2,285,050
1975	March 26, 1975	73,800	36,228	6,340	895	3,171	6,930	127,364	118,869	0.93	1,126,078.02	525,396
1957	March 7, 1957	79,200	36,361	4,050	1,800	1,024	4,690	127,125	112,424	0.88	959,767.93	1,041,400
1959	February 20, 1959	67,300	46,902	1,830	662	1,404	4,840	122,938	105,502	0.86	797,067.77	3,127,847
1971	December 5, 1970	73,200	32,983	5,880	1,230	1,675	3,640	118,608	108,748	0.92	923,631.07	2,345,681
2002	January 6, 2002	65,567	34,528	725	194	3,097	4,224	108,335	91,437	0.84	802,131.57	461,516
1979	February 24, 1979	71,300	5,170	2,660	1,260	7,856	12,800	101,046	95,445	0.94	838,080.00	4,501,390
2005	May 22, 2005	74,100	6,668	1,590	2,090	151	12,100	96,699	90,974	0.94	769,348.76	331,279
2003	January 3, 2003	65,300	25,560	261	211	154	2,280	93,766	83,057	0.89	751,933.88	291,814
1968	February 25, 1968	66,200	18,648	1,350	838	1,251	4,120	92,407	88,976	0.96	798,412.56	578,604
1989	March 27, 1989	73,500	26	1,820	7	11	2,020	77,384	68,450	0.88	578,604.30	293,407
1966	January 10, 1966	53,600	4,085	377	436	536	5,350	64,384	61,741	0.96	596,854.21	398,339
1981	January 31, 1981	51,900	5,096	759	72	741	5,700	64,268	60,686	0.94	525,395.70	495,923
1964	January 23, 1964	52,200	2,841	2,780	624	455	3,110	62,010	54,099	0.87	399,078.35	1,300,621
2001	March 9, 2001	46,200	4,425	483	289	627	5,660	57,684	53,441	0.93	505,557.02	237,051
1992	February 17, 1992	46,800	2,456	1,290	177	1,516	5,110	57,349	53,943	0.94	495,923.31	2,229,884
1991	March 27, 1991	46,900	3,260	1,310	119	2,027	3,310	56,926	49,859	0.88	398,338.51	1,647,205
1961	February 14, 1961	49,500	1,750	228	111	36	960	52,585	51,222	0.97	455,516.03	3,641,897
1985	November 30, 1984	41,200	3,408	511	762	439	3,500	49,820	47,470	0.95	461,516.03	2,823,322
1987	March 16, 1987	38,000	1,686	840	91	443	3,000	44,060	40,764	0.93	331,279.34	991,787
1988	January 7, 1988	37,200	3,245	203	46	49	1,280	42,023	39,287	0.93	291,814.21	1,446,424
1990	January 16, 1990	36,900	25	284	45	30	1,370	38,654	33,325	0.86	293,406.94	505,557
1972	December 28, 1971	31,100	192	1,440	96	406	3,430	36,664	35,424	0.97	337,838.68	802,132
1994	February 10, 1994	29,900	1,686	190	150	64	2,780	34,770	29,317	0.84	237,050.58	751,934
1976	December 8, 1975	30,600	48	53	297	15	3,580	34,593	33,457	0.97	325,368.60	1,594,217
1977	January 5, 1977	13,700	3	76	37	12	1,080	14,908	13,128	0.88	122,449.59	769,349

Table 2-4: Summary of Delta Inflows

Sacramento + Yolo Bypass Inflows	WY 1956 - 1967, pre-Oroville Dam	WY 1968 - 2005, ~Existing Conditions	WY 1956 - 2005, Period of Record
Average Daily Inflow, cfs	26,430	28,671	28,088
Avg. Annual Precip., inches[1]	17.4	18.1	18
Max. Annual Precip., inches	27.7	34.5	35
Inflow Range	**Number of Inflows in Q-Range**		
0-100K	4564	12924	17488
100K-200K	152	466	618
200K-300K	28	96	124
300K-400K	3	19	22
400K-500K	2	5	7
>500K	0	4	4
sum =	4749	13514	18263
Inflow Range	**No. of Days per Year With Inflows in Q-range**		
0-100K	351.1	349.3	349.8
100K-200K	11.7	12.6	12.4
200K-300K	2.2	2.6	2.5
300K-400K	0.2	0.5	0.4
400K-500K	0.2	0.1	0.1
>500K	0.0	0.1	0.1
sum =	365.3	365.2	365.3

San Joaquin River Inflows	WY 1956 - 1978, pre-New Melones Dam	WY 1979 - 2005, ~Existing Conditions	WY 1956 - 2005, Period of Record
Average Daily Inflow, cfs	4,416	4,809	4,416
Avg. Annual Precip., inches[2]	13.9	14.9	14.3
Max. Annual Precip., inches	25.9	27.5	27.5
Inflow Range	**Number of Inflows in Q-range**		
0-10K	8037	8270	16307
10K-20K	393	697	1090
20K-30K	247	336	583
30K-40K	74	171	245
40K-50K	15	22	37
>50K	0	1	1
sum =	8766	9497	18263
Inflow Range	**No. of Days per Year With Inflows in Q-range**		
0-10K	334.9	318.1	326.1
10K-20K	16.4	26.8	21.8
20K-30K	10.3	12.9	11.7
30K-40K	3.1	6.6	4.9
40K-50K	0.6	0.8	0.7
>50K	0.0	0.0	0.0
sum =	365.3	365.3	365.3

1. Precipitation data from the Sacramento Airport, Station 47630
2. Friant Governmant Camp

Table 2-5: Statistical Analysis of Annual Peak Inflows

Annual Peak Delta Inflows - Sacramento River & Yolo		
Annual Peak Inflows - Statistical Parameters	**WY 1956 - 1967, pre-Oroville Dam**	**WY 1968 - 2005, ~Existing Conditions**
No. of Years	12	38
Mean	188,164	160,107
Standard Deviation	128,500	140,928
Minimum	51,250	13,703
Median	137,681	108,106
Maximum	441,865	612,301
Distribution	Lognormal	
Statistical Test	t-Test (lognormal, equal variances)	
2-sided p-value	0.304	
Statistical Difference	No	

Annual Peak Delta Inflows - San Joaquin River		
Annual Peak Inflows - Statistical Parameters	**WY 1956 - 1978, pre-New Melones Dam**	**WY 1979 - 2005, ~Existing Conditions**
No. of Years	23	27
Mean	7,402	10,431
Standard Deviation	8,674	9,587
Minimum	960	1,280
Median	4,690	5,700
Maximum	41,700	41,800
Distribution	Lognormal	
Statistical Test	t-Test (lognormal, equal variances)	
2-sided p-value	0.227	
Statistical Difference	No	

Table 3-1: Annual Peak Delta Inflows (cfs)

Water Year	Water Year - Oct. 1 to Sept. 30	High Runoff Season Dec 16 to Apr 15	Low Runoff Season Oct 1 to Dec 15, Apr 16 to Sep 30
1956	383,322	383,322	80,086
1957	127,125	127,125	77,800
1958	278,826	278,826	127,867
1959	122,938	122,938	18,357
1960	142,860	142,860	21,479
1961	52,585	52,585	35,461
1962	157,492	157,492	35,160
1963	350,859	350,859	232,438
1964	62,010	62,010	42,188
1965	470,122	470,122	90,923
1966	64,384	64,384	38,415
1967	237,831	237,831	115,781
1968	92,407	92,407	25,433
1969	283,710	283,710	86,471
1970	383,921	383,921	26,488
1971	118,608	110,400	118,608
1972	36,664	36,664	22,654
1973	222,801	222,801	43,742
1974	276,092	276,092	123,106
1975	127,364	127,364	44,033
1976	34,593	30,651	34,593
1977	14,908	14,908	12,438
1978	174,450	174,450	70,752
1979	101,046	101,046	27,774
1980	339,008	339,008	33,394
1981	64,268	64,268	33,434
1982	238,395	238,395	197,768
1983	422,213	422,213	127,334
1984	351,622	351,622	169,189
1985	49,820	44,937	49,820
1986	661,272	661,272	48,018
1987	44,060	44,060	26,604
1988	42,023	42,023	28,941
1989	77,384	77,384	30,508
1990	38,654	38,654	23,052
1991	56,926	56,926	13,399
1992	57,349	57,349	13,870
1993	143,649	143,649	54,362
1994	34,770	34,770	29,893
1995	387,177	387,177	176,174
1996	207,020	207,020	98,021
1997	561,989	561,989	130,890
1998	323,012	323,012	112,420
1999	141,418	141,418	69,997
2000	168,766	168,766	43,293
2001	57,684	57,684	18,567
2002	108,335	108,335	39,772
2003	93,766	93,766	71,627
2004	186,184	186,184	34,270
2005	96,699	73,956	96,699

Table 3-2

Results of Log Pearson Type III Frequency Analyses

Probability	Inflows For Various Percent Confidence That The Inflow Will Not Be Exceeded												
	CL = 99%	CL = 97.5%	CL = 95%	CL = 90%	CL = 80%	CL = 60%	CL = 50%	CL = 40%	CL = 20%	CL = 10%	CL = 5%	CL = 2.5%	CL = 1%
All Seasons Inflow													
0.5000	183,628	174,123	167,003	159,301	150,600	139,862	135,551	131,292	121,982	115,391	110,149	105,728	100,438
0.2000	417,743	384,177	362,404	340,001	316,076	288,481	280,047	267,913	246,965	232,973	222,322	213,661	205,125
0.1000	646,984	583,006	543,290	503,306	461,634	414,947	402,011	381,158	347,674	325,861	309,564	296,514	284,711
0.0500	925,781	819,574	755,468	691,963	626,943	555,619	536,997	505,080	455,965	424,523	401,337	382,966	367,245
0.0400	1,026,698	904,163	830,738	758,322	684,543	604,074	583,366	547,383	492,578	457,658	431,996	411,722	394,606
0.0250	1,257,855	1,096,264	1,000,731	907,312	813,021	711,305	685,788	640,424	572,582	529,736	498,454	473,871	453,614
0.0200	1,376,716	1,194,262	1,087,010	982,520	877,483	764,716	736,715	686,503	611,966	565,071	530,929	504,158	482,312
0.0100	1,784,960	1,527,536	1,378,571	1,234,957	1,092,240	941,059	904,505	837,586	740,151	679,497	635,677	601,532	574,362
0.0050	2,255,260	1,906,317	1,707,080	1,516,767	1,329,544	1,133,535	1,087,120	1,000,928	877,353	801,129	746,428	704,032	670,944
0.0020	2,978,735	2,480,798	2,200,802	1,936,227	1,679,002	1,413,366	1,351,820	1,236,059	1,072,812	973,177	902,221	847,564	805,745
0.0010	3,607,958	2,974,111	2,621,311	2,290,391	1,971,236	1,644,691	1,570,048	1,428,709	1,231,467	1,111,939	1,027,254	962,289	913,176
0.0005	4,312,097	3,520,576	3,084,102	2,677,476	2,288,198	1,893,304	1,804,086	1,634,300	1,399,532	1,258,192	1,158,523	1,082,350	1,025,346
0.0001	6,257,320	5,006,780	4,330,189	3,708,698	3,122,771	2,538,809	2,409,770	2,162,386	1,826,400	1,626,823	1,487,440	1,381,729	1,304,080
High Inflow Season													
0.5000	181,568	172,677	165,544	157,831	149,124	138,385	134,031	129,820	120,522	113,944	108,714	104,307	99,311
0.2000	413,058	384,136	362,145	339,533	315,401	287,591	276,906	266,882	245,805	231,739	221,037	212,338	202,824
0.1000	639,727	585,479	545,194	504,669	462,468	415,235	397,502	381,085	347,276	325,268	308,836	295,684	281,518
0.0500	915,397	825,972	760,721	696,137	630,079	557,696	530,974	506,465	456,730	424,919	401,476	382,913	363,125
0.0400	1,015,182	912,153	837,341	763,625	688,596	606,861	576,822	549,344	493,801	458,443	432,477	411,975	390,180
0.0250	1,243,746	1,108,170	1,010,641	915,363	819,299	715,802	678,096	643,769	574,902	531,453	499,753	474,855	448,526
0.0200	1,361,275	1,208,309	1,098,719	992,060	884,962	770,130	728,451	690,588	614,872	567,283	532,662	505,531	476,903
0.0100	1,764,939	1,549,465	1,396,870	1,249,918	1,104,061	949,770	894,360	844,316	745,139	683,467	638,948	604,280	567,919
0.0050	2,229,964	1,938,146	1,733,590	1,538,429	1,346,685	1,146,245	1,074,926	1,010,841	884,829	807,192	751,524	708,407	663,418
0.0020	2,945,324	2,529,142	2,240,895	1,968,875	1,704,783	1,432,499	1,336,657	1,251,046	1,084,220	982,528	910,174	854,479	796,708
0.0010	3,567,490	3,037,795	2,673,925	2,333,085	2,004,848	1,669,586	1,552,438	1,448,212	1,246,349	1,124,182	1,037,709	971,422	902,933
0.0005	4,263,731	3,602,278	3,151,331	2,731,820	2,330,828	1,924,779	1,783,850	1,658,929	1,418,332	1,273,682	1,171,779	1,093,960	1,013,845
0.0001	6,187,136	5,141,778	4,440,231	3,796,821	3,191,257	2,588,905	2,382,741	2,201,376	1,856,069	1,651,259	1,508,377	1,400,104	1,289,453
Low Inflow Season													
0.5000	68,727	65,878	63,574	61,061	58,198	54,623	53,160	51,736	48,561	46,287	44,462	42,911	41,138
0.2000	139,955	131,575	125,144	118,473	111,284	102,898	99,645	96,576	90,066	85,675	82,306	79,549	76,513
0.1000	207,931	192,620	181,139	169,485	157,226	143,338	138,074	133,174	122,995	116,301	111,264	107,208	102,812
0.0500	290,229	265,260	246,858	228,475	209,477	188,403	180,547	173,303	158,476	148,897	141,785	136,120	130,045
0.0400	320,067	291,342	270,273	249,319	227,768	204,001	195,181	187,069	170,532	159,899	152,032	145,783	139,102
0.0250	388,659	350,886	323,437	296,368	268,789	238,708	227,642	217,513	197,019	183,960	174,362	166,780	158,715
0.0200	424,091	381,448	350,586	320,264	289,499	256,103	243,863	232,684	210,139	195,828	185,340	177,074	168,302
0.0100	546,819	486,453	443,268	401,289	359,189	314,108	297,761	282,918	253,258	234,632	221,091	210,485	199,300
0.0050	690,367	607,903	549,521	493,307	437,513	378,485	357,283	338,130	300,165	276,549	259,496	246,215	232,282
0.0020	916,000	796,528	712,991	633,460	555,491	474,173	445,288	419,355	368,429	337,098	314,656	297,288	279,181
0.0010	1,117,030	962,759	855,816	754,796	656,598	555,188	519,441	487,483	425,124	387,048	359,923	339,023	317,321
0.0005	1,347,193	1,151,399	1,016,766	890,518	768,770	644,191	600,590	561,764	486,453	440,790	408,423	383,584	357,892
0.0001	1,999,908	1,678,991	1,462,024	1,261,661	1,071,627	880,862	815,089	756,991	645,681	579,164	532,504	496,990	460,544

Table 3-3: Parameters Used in Log-Pearson Type III Distribution

Season	Mean	Standard Deviation	Skew	Weighted Skew
All	5.12	0.383	-0.194	0.223
High	5.11	0.387	-0.184	-0.216
Low	4.72	0.325	0.0645	-0.0323

Weighted skew is a function of the generalized skew (-0.3000) and Mean Square Error of Generalized Skew (see p. 13, of Bulletin 17B)

Table 3-4: PMF Inflows Into The Delta

Confidence Limits:		PMF Values For Delta, Area (mi.2) = 42,460
%	K	
1%	-2.32634	1,799,962
2.5%	-1.95996	2,083,139
5%	-1.64485	2,362,072
10%	-1.28155	2,730,328
20%	-0.84162	3,253,928
40%	-0.25335	4,114,277
50%	0.00000	4,551,679
60%	*0.25335*	5,035,583
80%	0.84162	6,367,007
90%	1.28155	7,588,020
95%	1.64485	8,771,022
97.5%	1.95996	9,945,463
99%	*2.32634*	11,510,122

Table 3-5: Inflow Ranges (Bins) and Confidence Limit Probabilities for the High Inflow Season - Year 2000

						5% Confidence Limit		20% Confidence Limit		50% Confidence Limit		80% Confidence Limit		95% Confidence Limit	
Bin #	LN (Lower Value)	LN (Upper Value)	Lower Value	Upper Value	Designated Bin Value(1)	Frequency of Exceeding Lower Value	Frequency of Being in Bin	Frequency of Exceeding Lower Value	Frequency of Being in Bin	Frequency of Exceeding Lower Value	Frequency of Being in Bin	Frequency of Exceeding Lower Value	Frequency of Being in Bin	Frequency of Exceeding Lower Value	Frequency of Being in Bin
			0	30,045		1.000		1.000		1.000		1.000		1.000	
1	10.310438	10.581243	30,045	39,389	34,401	1.000	0.000	0.980	0.020	0.940	0.060	0.900	0.100	0.880	0.120
2	10.581243	10.852048	39,389	51,640	45,100	0.970	0.030	0.935	0.045	0.865	0.075	0.795	0.105	0.760	0.120
3	10.852048	11.122853	51,640	67,701	59,127	0.920	0.050	0.873	0.062	0.780	0.085	0.687	0.108	0.640	0.120
4	11.122853	11.393658	67,701	88,757	77,517	0.840	0.080	0.788	0.085	0.685	0.095	0.582	0.105	0.530	0.110
5	11.393658	11.664463	88,757	116,362	101,627	0.735	0.105	0.678	0.110	0.565	0.120	0.452	0.130	0.395	0.135
6	11.664463	11.935268	116,362	152,553	133,234	0.617	0.118	0.559	0.119	0.445	0.120	0.331	0.121	0.273	0.122
7	11.935268	12.206073	152,553	200000	174,673	0.490	0.127	0.401	0.158	0.353	0.092	0.262	0.069	0.216	0.057
8	12.206073	12.476878	200,000	262,204	229,000	0.360	0.130	0.283	0.118	0.225	0.128	0.174	0.088	0.138	0.078
9	12.476878	12.747683	262,204	343,754	300,223	0.235	0.125	0.167	0.116	0.130	0.095	0.103	0.071	0.078	0.060
10	12.747683	13.018488	343,754	450,669	393,598	0.145	0.090	0.105	0.062	0.076	0.054	0.053	0.050	0.036	0.042
11	13.018488	13.289293	450,669	590,835	516,015	0.085	0.060	0.059	0.046	0.038	0.038	0.023	0.030	0.014	0.022
12	13.289293	13.560098	590,835	774,597	676,505	0.047	0.038	0.029	0.030	0.017	0.021	0.009	0.014	0.004	0.010
13	13.560098	13.830903	774,597	1,015,511	886,911	0.024	0.023	0.013	0.016	0.006	0.011	0.003	0.006	0.001	0.003
14	13.830903	14.101708	1,015,511	1,331,355	1,162,758	0.011	0.013	0.004	0.009	0.002	0.004	0.001	0.002	0.000	0.001
15	14.101708	14.372513	1,331,355	1,745,432	1,524,398	0.004	0.007	0.001	0.003	0.001	0.001	0.000	0.001	0.000	0.000
16	14.372513	14.643318	1,745,432	2,288,296	1,998,516	0.001	0.003	0.000	0.001	0.000	0.001	0.000	0.000	0.000	0.000
17	14.643318	14.914123	2,288,296	3,000,000	2,620,093	0.000	0.001	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

Table 3-6: Probabilities of Annual Frequency of Total Delta Inflow (TDI) Bins

Bin #	Lower Value	Upper Value	Designated Bin Value	CL Bin #1 - 20% Probability (0-20%)	CL Bin #2 - 30% Probability (20-50%)	CL Bin #3 - 30% Probability (50-80%)	CL Bin #4 - 20% Probability (80-100%)
	0	30,045					
1	30,045	39,389	34,401	0.01000	0.04000	0.08000	0.11000
2	39,389	51,640	45,100	0.03750	0.06000	0.09000	0.11250
3	51,640	67,701	59,127	0.05600	0.07350	0.09650	0.11400
4	67,701	88,757	77,517	0.08250	0.09000	0.10000	0.10750
5	88,757	116,362	101,627	0.10750	0.11500	0.12500	0.13250
6	116,362	152,553	133,234	0.11850	0.11950	0.12050	0.12150
7	152,553	200000	174,673	0.14250	0.12500	0.08050	0.06300
8	200,000	262,204	229,000	0.12400	0.12300	0.10800	0.08300
9	262,204	343,754	300,223	0.12050	0.10550	0.08300	0.06550
10	343,754	450,669	393,598	0.07600	0.05800	0.05200	0.04600
11	450,669	590,835	516,015	0.05300	0.04200	0.03400	0.02600
12	590,835	774,597	676,505	0.03400	0.02550	0.01750	0.01200
13	774,597	1,015,511	886,911	0.01950	0.01350	0.00850	0.00450
14	1,015,511	1,331,355	1,162,758	0.01100	0.00650	0.00300	0.00150
15	1,331,355	1,745,432	1,524,398	0.00500	0.00200	0.00100	0.00050
16	1,745,432	2,288,296	1,998,516	0.00200	0.00100	0.00050	0.00000
17	2,288,296	3,000,000	2,620,093	0.00050	0.00000	0.00000	0.00000
				1.00000	1.00000	1.00000	1.00000

Table 4-1 Summary of Data Used for Flow Pattern Analysis for Inflows to Delta

Statistic/Delta Inflow	SAC	YOLO	CSMR	MOKE	MISC	SJR	Total
Average	86,718	147,538	6,865	3,361	5,787	23,991	274,261
Standard Deviation	7,294	68,429	6,555	1,520	4,326	11,882	75,245
Coefficient of Variation	0.084	0.46	0.95	0.45	0.74	0.49	0.27
1st Quartile	81,200	100,739	3,260	2,810	3,000	14,950	221,723
2nd Quartile (median)	86,100	131,803	4,830	3,380	4,804	22,900	253,531
3rd Quartile	91,750	174,671	7,800	4,365	7,553	33,650	303,439
Minimum	69,400	58,449	1,200	57	146	1,450	200,568
Maximum	115,000	499,301	53,600	14,200	30,532	54,300	661,272
Number of data points	251	251	251	251	251	251	251

Table 4-2 Results of Logistic Regressions

River	a (Slope)	b (Intercept)	r^2	Standard Error of Regression
Sacramento + Yolo Bypass	.563	-5.21	0.054	0.530
San Joaquin River	0.430	-4.173	0.075	0.709
Miscellaneous Flows	0.379	-4.453	0.071	0.665
Cosumnes River	1.116	-9.670	0.358	0.714

Table 4-3 Comparison Between Observed and Predicted Flows in Delta Inflows

	Statistic	Yolo ByPass	Sacramento River	San Joaquin River	Miscellaneous Flows	Cosumnes River	Mokelumne River
Average	Observed	147,538	86,718	23,991	5,787	6,865	3,361
	Predicted	150,213	86,877	21,898	5,329	6,436	3,507
	Percent Error	-1.81	-0.18	8.72	7.90	6.25	4.35
Median	Observed	131,803	86,100	22,900	4,804	4,830	3,380
	Predicted	131,736	85,779	21,074	5,179	6,270	3,494
	Percent Error	0.05	0.37	7.98	-7.80	-29.82	-3.38

Table 5-1: Probability of San Francisco Tide Elevation, High Delta Inflow Season

Bin No.	Max. Bin Tide, feet	Min. Bin Tide, feet	Avg. Bin Tide, feet	Probability of Occurrence High Inflow Season	Probability of Exceedance High Inflow Season
1	3.75	4.00	3.875	0.0005	0.9995
2	4.00	4.25	4.125	0.0015	0.9980
3	4.25	4.50	4.375	0.0044	0.9936
4	4.50	4.75	4.625	0.0184	0.9752
5	4.75	5.00	4.875	0.0444	0.9308
6	5.00	5.25	5.125	0.0877	0.8431
7	5.25	5.50	5.375	0.1243	0.7188
8	5.50	5.75	5.625	0.1548	0.5640
9	5.75	6.00	5.875	0.1410	0.4230
10	6.00	6.25	6.125	0.1360	0.2870
11	6.25	6.50	6.375	0.1072	0.1798
12	6.50	6.75	6.625	0.0738	0.1059
13	6.75	7.00	6.875	0.0487	0.0572
14	7.00	7.25	7.125	0.0293	0.0280
15	7.25	7.50	7.375	0.0145	0.0135
16	7.50	7.75	7.625	0.0067	0.0067
17	7.75	8.00	7.875	0.0041	0.0026
18	8.00	8.25	8.125	0.0018	0.0008
19	8.25	8.50	8.375	0.0003	0.0005
20	8.50	8.75	8.625	0.0003	0.0002
21	8.75	9.00	8.875	0.0000	0.0002
22	9.00	9.25	9.125	0.0002	0.0000

Table 5-2: Hydraulic Gradients Associated With Low (August) Flows

Station Name	Number of August Tide Cycle Calculations	Mean August Stage @ Station, feet NAVD 88	August MSL @ Golden Gate, feet NAVD 88	Golden Gate minus Station Elevation, feet	Approx. Hyd. Gradient to MAL Station x 10^{-5}
Western Delta					
BDL	3	4.02	3.38	0.64	0.20
ROR	5	4.04	3.33	0.71	0.57
MAL	4	3.91	3.37	0.54	N/A
North Central Delta					
BEN	5	5.59	3.31	2.29	0.66
GSS	3	5.11	3.38	1.73	0.76
North Delta					
FPT	5	6.73	3.26	3.47	1.29
SSS	2	6.36	3.33	3.03	1.69
LIS	4	5.66	3.27	2.39	0.88
South Delta - Middle River					
MTB	4	5.01	3.37	1.64	0.45
MHR	3	5.28	3.38	1.90	0.50
South Delta - Old River					
OLD	5	4.78	3.25	1.53	0.45
ORB	5	4.56	3.36	1.21	0.44
BAC	5	4.80	3.33	1.47	0.81
Southeast Delta - San Joaquin River					
SJL	3	5.39	3.31	2.09	0.75
VNI	5	4.30	3.27	1.03	0.31

Table 5-3: Station Adjustments to NAVD 88 Datum

Station Name	Avg. August Stage @ Station, feet	Avg. August MSL @ Golden Gate, feet	August MSL @ Golden Gate minus August Stage @ Station, feet	Stage Adjustment for August Inflows, feet	Total Station Adjustment for NAVD 88 Datum, feet
Western Delta					
BDL	4.02	3.38	0.64	0.64	0.00
ROR	4.04	3.33	0.71	0.71	0.00
MAL	1.40	3.91	-1.98	0.54	2.51
North Central Delta					
BEN	5.59	3.31	2.29	2.29	0.00
GSS	5.11	3.38	1.73	1.73	0.00
North Delta					
FPT	4.26	3.26	1.00	3.47	2.47
SSS	3.93	3.33	0.61	3.04	2.43
LIS	5.66	3.27	2.39	2.39	0.00
South Delta - Middle River					
MTB	5.01	3.37	1.64	1.64	0.00
MHR	5.28	3.38	1.90	1.90	0.00
South Delta - Old River					
OLD	4.78	3.25	1.53	1.53	0.00
ORB	4.56	3.35	1.21	1.21	0.00
BAC	4.71	3.33	1.38	1.38	0.00
Southeast Delta - San Joaquin River					
SJL	5.39	3.37	2.02	2.02	0.00
VNI	5.02	3.27	1.75	1.75	0.00

Table 5-4: Estimated Coefficients "a" Through "g" in Equations 5-1 and 5-2

Station ID	a (Tide)	b (Sac)	c (Yolo)	d (Sjr)	e (Csmr)	f (Moke)	g (Misc)	Samples Used	Avg Error	Avg Abs. Error	Max Abs. Error
West Delta											
MAL	0.91	0.000247	NA	0.000363	0.000385	0.000000	0.000000	730	0.00	0.02	0.93
BDL	1.00	0.000123	NA	0.000696	0.000566	0.000000	0.000102	205	0.00	0.16	0.57
ROR	0.94	0.000302	NA	0.000148	0.000337	0.000000	0.000001	373	0.00	0.29	1.35
North Central Delta											
BEN	0.38	0.002020	0.000047	0.000750	0.013245	0.010418	0.006022	684	0.00	0.74	5.34
GSS	0.34	0.005067	0.000201	0.000000	0.000000	0.007334	0.000000	52	0.00	0.11	0.56
North Delta											
FPT	0.00	0.009705	0.000520	0.000000	0.001266	0.001466	0.000660	783	0.00	0.45	2.00
SSS	0.19	0.006071	0.000162	0.000003	0.000368	0.003880	0.000000	56	0.00	0.15	0.47
LIS	0.67	0.004997	0.001708	0.002487	0.000000	0.000000	0.000000	129	0.00	0.91	6.94
South Delta - Middle River											
MHR	0.88	0.000431	NA	0.002279	0.002543	0.000000	0.000000	105	0.00	0.21	0.21
MTB	0.90	0.000312	NA	0.001652	0.001220	0.000000	0.000000	123	0.00	0.22	1.21
South Delta - Old River											
OLD	0.81	0.000294	NA	0.002717	0.002480	0.000000	0.000000	85	0.00	0.24	1.05
BAC	1.00	0.000306	NA	0.000113	0.003236	0.000000	0.000000	100	0.00	0.32	1.35
ORB	0.79	0.000531	NA	0.001602	0.002982	0.001474	0.000000	109	0.00	0.20	0.77
Southeast Delta - San Joaquin River											
SJL	0.77	0.000181	NA	0.009743	0.001596	0.000000	0.000000	99	0.00	0.29	1.14
VNI	0.97	0.000387	NA	0.000925	0.000328	0.000000	0.000000	477	0.00	0.17	0.58

Note 1: Error = Measured - Predicted

Table 6-1: Probabilities - Future Climate Scenarios

7-Day Total Watershed Runoff	Probability of Exceedance, Year 2000	Probability of Exceedance, Year 2025	Probability of Exceedance, Year 2050	Probability of Exceedance, Year 2075	Probability of Exceedance, Year 2100 (Extrapolated)
Climate Scenario Sresb1-gfdl, 50% Confidence Limit					
1,362,410	0.50000	0.38107	0.49500	0.49500	0.49500
2,487,932	0.20000	0.17814	0.21000	0.22000	0.23000
3,376,047	0.10000	0.09776	0.11500	0.11800	0.12100
4,322,867	0.05000	0.05156	0.06500	0.07000	0.07500
4,641,862	0.04000	0.04157	0.05500	0.06000	0.06500
5,337,778	0.02500	0.02597	0.03570	0.04050	0.04530
5,679,954	0.02000	0.02061	0.02800	0.03400	0.04000
6,793,140	0.01000	0.00972	0.01650	0.01980	0.02310
7,985,137	0.00500	0.00434	0.00900	0.01200	0.01500
9,687,205	0.00200	0.00138	0.00415	0.00560	0.00705
11,073,852	0.00100	0.00054	0.00240	0.00360	0.00480
12,548,689	0.00050	0.00020	0.00130	0.00198	0.00266
16,326,850	0.00010	0.00002	0.00039	0.00056	0.00074
Climate Scenario Sresb1-ncar, 50% Confidence Limit					
1,265,807	0.50000	0.40677	0.58000	0.60000	0.62000
2,284,426	0.20000	0.20439	0.37000	0.42000	0.47000
3,059,426	0.10000	0.12108	0.23000	0.30800	0.38600
3,861,594	0.05000	0.07042	0.14500	0.20000	0.25500
4,126,830	0.04000	0.05887	0.12800	0.17500	0.22200
4,697,370	0.02500	0.04004	0.10000	0.14000	0.18000
4,974,095	0.02000	0.03321	0.08800	0.12700	0.16600
5,858,156	0.01000	0.01827	0.06000	0.09200	0.12400
6,779,960	0.00500	0.00980	0.04000	0.07000	0.10000
8,056,907	0.00200	0.00414	0.02350	0.04500	0.06650
9,066,883	0.00100	0.00209	0.01650	0.03500	0.05350
10,114,551	0.00050	0.00103	0.01100	0.02500	0.03900
12,689,828	0.00010	0.00018	0.00450	0.01280	0.02110
Climate Scenario Sresa2-gfdl, 50% Confidence Limit					
1,313,882	0.50000	0.39377	0.54000	0.48000	0.42000
2,411,546	0.20000	0.18757	0.28000	0.23000	0.18000
3,252,967	0.10000	0.10624	0.14700	0.13000	0.11300
4,126,932	0.05000	0.05886	0.08500	0.08000	0.07500
4,416,364	0.04000	0.04841	0.07173	0.06823	0.06474
5,039,498	0.02500	0.03177	0.05198	0.05230	0.05263
5,341,945	0.02000	0.02590	0.04445	0.04597	0.04748
6,308,805	0.01000	0.01348	0.02697	0.03043	0.03388
7,317,531	0.00500	0.00682	0.01601	0.01978	0.02355
8,715,140	0.00200	0.00265	0.00777	0.01090	0.01402
9,820,289	0.00100	0.00126	0.00439	0.00680	0.00921
10,966,159	0.00050	0.00058	0.00243	0.00417	0.00591
13,779,367	0.00010	0.00009	0.00057	0.00125	0.00194
Climate Scenario Sresa2-ncar, 50% Confidence Limit					
1,255,258	0.50000	0.40968	0.60000	0.60000	0.60000
2,354,395	0.20000	0.19495	0.29000	0.33500	0.38000
3,245,910	0.10000	0.10674	0.13200	0.17500	0.21800
4,215,011	0.05000	0.05546	0.07000	0.10750	0.14500
4,545,318	0.04000	0.04437	0.06500	0.08970	0.11440
5,271,974	0.02500	0.02716	0.03400	0.06350	0.09300
5,632,110	0.02000	0.02129	0.02700	0.05270	0.07840
6,815,802	0.01000	0.00957	0.01350	0.03080	0.04810
8,101,898	0.00500	0.00401	0.00610	0.01780	0.02950
9,968,069	0.00200	0.00114	0.00240	0.00810	0.01380
11,511,655	0.00100	0.00040	0.00110	0.00480	0.00850
13,174,150	0.00050	0.00013	0.00051	0.00280	0.00509
17,520,125	0.00010	0.00001	0.00007	0.00075	0.00143

Table 6-2: Delta Inflow Probabilities

Climate Scenario Sresb1-gfdl			
Discharge, cfs	Probability of Exceedance, Year 2000	Probability of Exceedance, Year 2050	Probability of Exceedance, Year 2100
Confidence Limit = 95%			
165,544	0.50000	0.49000	0.50000
362,145	0.20000	0.22000	0.24600
545,194	0.10000	0.11800	0.13200
760,721	0.05000	0.06600	0.08400
837,341	0.04000	0.05500	0.07200
1,010,641	0.02500	0.03600	0.04800
1,098,719	0.02000	0.03100	0.03900
1,396,870	0.01000	0.01700	0.02400
1,733,590	0.00500	0.00940	0.01560
2,240,895	0.00200	0.00435	0.00765
2,673,925	0.00100	0.00250	0.00480
3,151,331	0.00050	0.00130	0.00300
4,440,231	0.00010	0.00040	0.00064
Confidence Limit = 80%			
149,124	0.50000	0.49000	0.50000
315,401	0.20000	0.21500	0.24500
462,468	0.10000	0.11500	0.12500
630,079	0.05000	0.07000	0.08600
688,596	0.04000	0.05350	0.06950
819,299	0.02500	0.03600	0.04500
884,962	0.02000	0.03000	0.04000
1,104,061	0.01000	0.01700	0.02300
1,346,685	0.00500	0.00910	0.01530
1,704,783	0.00200	0.00435	0.00765
2,004,848	0.00100	0.00240	0.00470
2,330,828	0.00050	0.00130	0.00270
3,191,257	0.00010	0.00039	0.00071
Confidence Limit = 50%			
134,031	0.50000	0.49500	0.49500
276,906	0.20000	0.21000	0.23000
397,502	0.10000	0.11500	0.12100
530,974	0.05000	0.06500	0.07500
576,822	0.04000	0.05500	0.06500
678,096	0.02500	0.03570	0.04530
728,451	0.02000	0.02800	0.04000
894,360	0.01000	0.01650	0.02310
1,074,926	0.00500	0.00900	0.01500
1,336,657	0.00200	0.00415	0.00705
1,552,438	0.00100	0.00240	0.00480
1,783,850	0.00050	0.00130	0.00266
2,382,741	0.00010	0.00039	0.00074
Confidence Limit = 20%			
120,522	0.50000	0.48000	0.48000
245,805	0.20000	0.21000	0.22000
347,276	0.10000	0.11000	0.13000
456,730	0.05000	0.06100	0.07900
493,801	0.04000	0.05000	0.07000
574,902	0.02500	0.03500	0.04300
614,872	0.02000	0.02750	0.03750
745,139	0.01000	0.01600	0.02200
884,829	0.00500	0.00850	0.01350
1,084,220	0.00200	0.00400	0.00720
1,246,349	0.00100	0.00235	0.00425
1,418,332	0.00050	0.00125	0.00235
1,856,069	0.00010	0.00040	0.00110
Confidence Limit = 5%			
108,714	0.50000	0.49000	0.45000
221,037	0.20000	0.20500	0.20500
308,836	0.10000	0.11000	0.12000
401,476	0.05000	0.06000	0.07000
432,477	0.04000	0.05000	0.06000
499,753	0.02500	0.03450	0.04150
532,662	0.02000	0.02850	0.03550
638,948	0.01000	0.01530	0.02170
751,524	0.00500	0.00820	0.01280
910,174	0.00200	0.00400	0.00700
1,037,709	0.00100	0.00230	0.00370
1,171,779	0.00050	0.00120	0.00240
1,508,377	0.00010	0.00036	0.00074

Climate Scenario Sresb1-ncar			
Discharge, cfs	Probability of Exceedance, Year 2000	Probability of Exceedance, Year 2050	Probability of Exceedance, Year 2100
Confidence Limit = 95%			
165,544	0.50000	0.58000	0.66000
362,145	0.20000	0.37800	0.48200
545,194	0.10000	0.23500	0.39100
760,721	0.05000	0.14100	0.26300
837,341	0.04000	0.12800	0.22600
1,010,641	0.02500	0.09800	0.17600
1,098,719	0.02000	0.08500	0.16500
1,396,870	0.01000	0.06000	0.12000
1,733,590	0.00500	0.03900	0.09700
2,240,895	0.00200	0.02170	0.06030
2,673,925	0.00100	0.01580	0.04920
3,151,331	0.00050	0.01030	0.03570
4,440,231	0.00010	0.00420	0.01940
Confidence Limit = 80%			
149,124	0.50000	0.59000	0.61000
315,401	0.20000	0.37300	0.47700
462,468	0.10000	0.23500	0.38500
630,079	0.05000	0.14000	0.26000
688,596	0.04000	0.12500	0.23100
819,299	0.02500	0.10000	0.17800
884,962	0.02000	0.08500	0.16100
1,104,061	0.01000	0.05900	0.13100
1,346,685	0.00500	0.03900	0.10100
1,704,783	0.00200	0.02300	0.06100
2,004,848	0.00100	0.01610	0.04790
2,330,828	0.00050	0.01060	0.03340
3,191,257	0.00010	0.00430	0.02070
Confidence Limit = 50%			
134,031	0.50000	0.58000	0.62000
276,906	0.20000	0.37000	0.47000
397,502	0.10000	0.23000	0.38600
530,974	0.05000	0.14500	0.25500
576,822	0.04000	0.12800	0.22200
678,096	0.02500	0.10000	0.18000
728,451	0.02000	0.08800	0.16600
894,360	0.01000	0.06000	0.12400
1,074,926	0.00500	0.04000	0.10000
1,336,657	0.00200	0.02350	0.06650
1,552,438	0.00100	0.01650	0.05350
1,783,850	0.00050	0.01100	0.03900
2,382,741	0.00010	0.00450	0.02110
Confidence Limit = 20%			
120,522	0.50000	0.58000	0.60000
245,805	0.20000	0.36000	0.47000
347,276	0.10000	0.22700	0.37700
456,730	0.05000	0.14000	0.25000
493,801	0.04000	0.12500	0.22500
574,902	0.02500	0.10000	0.18000
614,872	0.02000	0.08500	0.16900
745,139	0.01000	0.06000	0.13000
884,829	0.00500	0.04000	0.10000
1,084,220	0.00200	0.02400	0.06600
1,246,349	0.00100	0.01700	0.05300
1,418,332	0.00050	0.01120	0.04080
1,856,069	0.00010	0.00465	0.02175
Confidence Limit = 5%			
108,714	0.50000	0.58000	0.60000
221,037	0.20000	0.36000	0.45000
308,836	0.10000	0.22700	0.35300
401,476	0.05000	0.14000	0.24600
432,477	0.04000	0.12510	0.22090
499,753	0.02500	0.09950	0.17850
532,662	0.02000	0.08700	0.16300
638,948	0.01000	0.05950	0.13050
751,524	0.00500	0.04000	0.10000
910,174	0.00200	0.02400	0.06600
1,037,709	0.00100	0.01700	0.05340
1,171,779	0.00050	0.01140	0.04020
1,508,377	0.00010	0.00470	0.02170

Climate Scenario Sresa2-gfdl			
Discharge, cfs	Probability of Exceedance, Year 2000	Probability of Exceedance, Year 2050	Probability of Exceedance, Year 2100
Confidence Limit = 95%			
165,544	0.50000	0.54000	0.46000
362,145	0.20000	0.28000	0.22000
545,194	0.10000	0.14000	0.13000
760,721	0.05000	0.08200	0.08800
837,341	0.04000	0.06986	0.07012
1,010,641	0.02500	0.05229	0.05964
1,098,719	0.02000	0.04532	0.05491
1,396,870	0.01000	0.02838	0.04145
1,733,590	0.00500	0.01716	0.03019
2,240,895	0.00200	0.00836	0.01881
2,673,925	0.00100	0.00465	0.01264
3,151,331	0.00050	0.00250	0.00821
4,440,231	0.00010	0.00052	0.00266
Confidence Limit = 80%			
149,124	0.50000	0.54000	0.44000
315,401	0.20000	0.28500	0.20500
462,468	0.10000	0.14200	0.12400
630,079	0.05000	0.08300	0.08100
688,596	0.04000	0.07105	0.06823
819,299	0.02500	0.05227	0.05668
884,962	0.02000	0.04498	0.05163
1,104,061	0.01000	0.02768	0.03783
1,346,685	0.00500	0.01656	0.02687
1,704,783	0.00200	0.00804	0.01633
2,004,848	0.00100	0.00451	0.01083
2,330,828	0.00050	0.00246	0.00698
3,191,257	0.00010	0.00054	0.00227
Confidence Limit = 50%			
134,031	0.50000	0.54000	0.42000
276,906	0.20000	0.28000	0.18000
397,502	0.10000	0.14700	0.11300
530,974	0.05000	0.08500	0.07500
576,822	0.04000	0.07173	0.06474
678,096	0.02500	0.05198	0.05263
728,451	0.02000	0.04445	0.04748
894,360	0.01000	0.02697	0.03388
1,074,926	0.00500	0.01601	0.02355
1,336,657	0.00200	0.00777	0.01402
1,552,438	0.00100	0.00439	0.00921
1,783,850	0.00050	0.00243	0.00591
2,382,741	0.00010	0.00057	0.00194
Confidence Limit = 20%			
120,522	0.50000	0.54000	0.42000
245,805	0.20000	0.28500	0.16500
347,276	0.10000	0.14500	0.10900
456,730	0.05000	0.08410	0.06674
493,801	0.04000	0.07190	0.06016
574,902	0.02500	0.05144	0.04797
614,872	0.02000	0.04378	0.04292
745,139	0.01000	0.02627	0.02995
884,829	0.00500	0.01552	0.02045
1,084,220	0.00200	0.00755	0.01198
1,246,349	0.00100	0.00430	0.00781
1,418,332	0.00050	0.00241	0.00500
1,856,069	0.00010	0.00059	0.00166
Confidence Limit = 5%			
108,714	0.50000	0.53000	0.41000
221,037	0.20000	0.28200	0.15800
308,836	0.10000	0.14500	0.09500
401,476	0.05000	0.08428	0.06169
432,477	0.04000	0.07162	0.05513
499,753	0.02500	0.05072	0.04324
532,662	0.02000	0.04300	0.03842
638,948	0.01000	0.02559	0.02631
751,524	0.00500	0.01507	0.01772
910,174	0.00200	0.00736	0.01025
1,037,709	0.00100	0.00423	0.00666
1,171,779	0.00050	0.00240	0.00426
1,508,377	0.00010	0.00062	0.00143

Climate Scenario Sresa2-ncar			
Discharge, cfs	Probability of Exceedance, Year 2000	Probability of Exceedance, Year 2050	Probability of Exceedance, Year 2100
Confidence Limit = 95%			
165,544	0.50000	0.60000	0.60000
362,145	0.20000	0.27000	0.40000
545,194	0.10000	0.12500	0.18900
760,721	0.05000	0.06300	0.13500
837,341	0.04000	0.04800	0.12100
1,010,641	0.02500	0.03000	0.08800
1,098,719	0.02000	0.02280	0.07220
1,396,870	0.01000	0.01070	0.04530
1,733,590	0.00500	0.00500	0.02660
2,240,895	0.00200	0.00180	0.01320
2,673,925	0.00100	0.00084	0.00716
3,151,331	0.00050	0.00043	0.00437
4,440,231	0.00010	0.00006	0.00114
Confidence Limit = 80%			
149,124	0.50000	0.58000	0.62000
315,401	0.20000	0.28000	0.40000
462,468	0.10000	0.13000	0.22000
630,079	0.05000	0.06600	0.14300
688,596	0.04000	0.05200	0.12200
819,299	0.02500	0.03200	0.09060
884,962	0.02000	0.02500	0.07560
1,104,061	0.01000	0.01215	0.04645
1,346,685	0.00500	0.00560	0.02820
1,704,783	0.00200	0.00215	0.01325
2,004,848	0.00100	0.00096	0.00798
2,330,828	0.00050	0.00047	0.00478
3,191,257	0.00010	0.00008	0.00124
Confidence Limit = 50%			
134,031	0.50000	0.60000	0.60000
276,906	0.20000	0.29000	0.38000
397,502	0.10000	0.13200	0.21800
530,974	0.05000	0.07000	0.14500
576,822	0.04000	0.06500	0.11440
678,096	0.02500	0.03400	0.09300
728,451	0.02000	0.02700	0.07840
894,360	0.01000	0.01350	0.04810
1,074,926	0.00500	0.00610	0.02950
1,336,657	0.00200	0.00240	0.01380
1,552,438	0.00100	0.00110	0.00850
1,783,850	0.00050	0.00051	0.00509
2,382,741	0.00010	0.00007	0.00143
Confidence Limit = 20%			
120,522	0.50000	0.59000	0.59000
245,805	0.20000	0.29500	0.38500
347,276	0.10000	0.13500	0.22500
456,730	0.05000	0.07200	0.14800
493,801	0.04000	0.05800	0.12620
574,902	0.02500	0.03600	0.09400
614,872	0.02000	0.02950	0.08010
745,139	0.01000	0.01440	0.04960
884,829	0.00500	0.00660	0.03040
1,084,220	0.00200	0.00260	0.01480
1,246,349	0.00100	0.00119	0.00881
1,418,332	0.00050	0.00056	0.00505
1,856,069	0.00010	0.00010	0.00151
Confidence Limit = 5%			
108,714	0.50000	0.60000	0.60000
221,037	0.20000	0.26000	0.44000
308,836	0.10000	0.14300	0.22700
401,476	0.05000	0.07500	0.14500
432,477	0.04000	0.06300	0.10100
499,753	0.02500	0.03800	0.09400
532,662	0.02000	0.03100	0.08100
638,948	0.01000	0.01550	0.05010
751,524	0.00500	0.00700	0.03100
910,174	0.00200	0.00285	0.01555
1,037,709	0.00100	0.00127	0.00933
1,171,779	0.00050	0.00060	0.00574
1,508,377	0.00010	0.00013	0.00155

Table 6-3: Inflow Ranges (Bins) for Analysis of Future Conditions

Bin #	LN (Lower Value)	LN (Upper Value)	Lower Value	Upper Value	Designated Bin Value(1)
1	12.20607	12.42066	200,000	247,871	223,936
2	12.42066	12.63526	247,871	307,201	277,536
3	12.63526	12.84985	307,201	380,731	343,966
4	12.84985	13.06444	380,731	471,861	426,296
5	13.06444	13.27903	471,861	584,804	528,332
6	13.27903	13.49362	584,804	724,780	654,792
7	13.49362	13.70821	724,780	898,260	811,520
8	13.70821	13.92281	898,260	1,113,264	1,005,762
9	13.92281	14.13740	1,113,264	1,379,730	1,246,497
10	14.13740	14.35199	1,379,730	1,709,976	1,544,853
11	14.35199	14.56658	1,709,976	2,119,269	1,914,622
12	14.56658	14.78117	2,119,269	2,626,528	2,372,898
13	14.78117	14.99577	2,626,528	3,255,202	2,940,865
14	14.99577	15.21036	3,255,202	4,034,354	3,644,778
15	15.21036	15.42495	4,034,354	5,000,000	4,517,177

Table 6-4: Annual Probability of Exceedance

Upper & Lower Limits of Inflow Bins, cfs	Probability of Exceedance, CL = 95%	Probability of Exceedance, CL = 80%	Probability of Exceedance, CL = 50%	Probability of Exceedance, CL = 20%	Probability of Exceedance, CL = 5%	Upper & Lower Limits of Inflow Bins, cfs	Probability of Exceedance, CL = 95%	Probability of Exceedance, CL = 80%	Probability of Exceedance, CL = 50%	Probability of Exceedance, CL = 20%	Probability of Exceedance, CL = 5%
			Climate Scenario: Sresb1-gfdl						**Climate Scenario: Sresb1-ncar**		
Year 2100						**Year 2100**					
200,000	0.4530000	0.4190000	0.3760000	0.3070000	0.2540000	200,000	0.6280000	0.5680000	0.5480000	0.5170000	0.4750000
247,871	0.3880000	0.3400000	0.2770000	0.2170000	0.1680000	247,871	0.5820000	0.5300000	0.4970000	0.4680000	0.4190000
307,201	0.3090000	0.2560000	0.1910000	0.1550000	0.1210000	307,201	0.5280000	0.4830000	0.4470000	0.4140000	0.3550000
380,731	0.2290000	0.1780000	0.1315000	0.1110000	0.0795000	380,731	0.4700000	0.4350000	0.4000000	0.3400000	0.2200000
471,861	0.1650000	0.1205000	0.0910000	0.0745000	0.0488000	471,861	0.4260000	0.3780000	0.3150000	0.2370000	0.1950000
584,804	0.1180000	0.0935000	0.0635000	0.0410000	0.0280000	584,804	0.3680000	0.2940000	0.2180000	0.1760000	0.1470000
724,780	0.0900000	0.0620000	0.0405000	0.0240000	0.0143000	724,780	0.2830000	0.2160000	0.1670000	0.1360000	0.1070000
898,260	0.0695000	0.0390000	0.0230000	0.0128000	0.0073000	898,260	0.2190000	0.1580000	0.1230000	0.0970000	0.0680000
1,113,264	0.0381000	0.0225000	0.0137000	0.0065000	0.0028000	1,113,264	0.1630000	0.1300000	0.0950000	0.0625000	0.0420000
1,379,730	0.0247000	0.0146000	0.0063000	0.0026000	0.0014000	1,379,730	0.1220000	0.0970000	0.0627000	0.0430000	0.0270000
1,709,976	0.0160000	0.0077000	0.0032000	0.0013000	0.0007000	1,709,976	0.0987000	0.0607000	0.0425000	0.0300000	0.0125000
2,119,269	0.0092000	0.0037500	0.0015300	0.0007000	0.0002800	2,119,269	0.0675000	0.0415000	0.0285000	0.0130000	0.0042000
2,626,528	0.0050000	0.0019200	0.0006800	0.0003300	0.0000000	2,626,528	0.0503000	0.0283000	0.0165000	0.0055000	0.0003000
3,255,202	0.0027800	0.0008200	0.0003300	0.0000000	0	3,255,202	0.0340000	0.0200000	0.0085000	0.0017000	0
4,034,354	0.0013500	0.0004000	0.0000000	0	0	4,034,354	0.0243000	0.0126000	0.0039000	0	0
5,000,000	0.0005600	0.0000700	0.0000000	0	0	5,000,000	0.0141900	0.0050000	0.0004300	0	0
Year 2050						**Year 2050**					
200,000	0.4400000	0.4010000	0.3560000	0.3000000	0.2500000	200,000	0.5440000	0.5210000	0.4800000	0.4370000	0.3980000
247,871	0.3700000	0.3170000	0.2580000	0.2070000	0.1620000	247,871	0.4930000	0.4570000	0.4095000	0.3570000	0.3140000
307,201	0.2840000	0.2250000	0.1735000	0.1385000	0.1110000	307,201	0.4310000	0.3830000	0.3300000	0.2730000	0.2290000
380,731	0.2030000	0.1560000	0.1242000	0.0905000	0.0700000	380,731	0.3610000	0.3040000	0.2460000	0.1970000	0.1580000
471,861	0.1470000	0.1105000	0.0835000	0.0552000	0.0408000	471,861	0.2840000	0.2290000	0.1790000	0.1210000	0.1100000
584,804	0.1050000	0.0800000	0.0535000	0.0330000	0.0215000	584,804	0.2130000	0.1620000	0.1270000	0.0970000	0.0730000
724,780	0.0730000	0.0478000	0.0282000	0.0175000	0.0093000	724,780	0.1545000	0.1180000	0.0890000	0.0635000	0.0440000
898,260	0.0480000	0.0290000	0.0163000	0.0080000	0.0045000	898,260	0.1180000	0.0835000	0.0600000	0.0385000	0.0250000
1,113,264	0.0303000	0.0167000	0.0080000	0.0035000	0.0015000	1,113,264	0.0835000	0.0580000	0.0370000	0.0222000	0.0133000
1,379,730	0.0176000	0.0084500	0.0036000	0.0013800	0.0007000	1,379,730	0.0613000	0.0370000	0.0215000	0.0110000	0.0072000
1,709,976	0.0098000	0.0043500	0.0015000	0.0007000	0.0003000	1,709,976	0.0400000	0.0228000	0.0123000	0.0068000	0.0026000
2,119,269	0.0053000	0.0018500	0.0008000	0.0003500	0.0000000	2,119,269	0.0251000	0.0138000	0.0073000	0.0027000	0.0003700
2,626,528	0.0026500	0.0009300	0.0004000	0.0000000	0	2,626,528	0.0164000	0.0082200	0.0037000	0.0004600	0
3,255,202	0.0011900	0.0005300	0.0000700	0.0000000	0	3,255,202	0.0096500	0.0043500	0.0012000	0.0000000	0
4,034,354	0.0007000	0.0001300	0.0000000	0	0	4,034,354	0.0060000	0.0023000	0.0002800	0	0
5,000,000	0.0003500	0.0000000	0.0000000	0	0	5,000,000	0.0033000	0.0005600	0.0000000	0	0
Year 2000						**Year 2000**					
200,000	0.4950000	0.4030000	0.3530000	0.2990000	0.2470000	200,000	0.4950000	0.4030000	0.3530000	0.2990000	0.2470000
247,871	0.3650000	0.3100000	0.2510000	0.1970000	0.1550000	247,871	0.3650000	0.3100000	0.2510000	0.1970000	0.1550000
307,201	0.2572000	0.2100000	0.1620000	0.1270000	0.1028000	307,201	0.2572000	0.2100000	0.1620000	0.1270000	0.1028000
380,731	0.1820000	0.1390000	0.1095000	0.0805000	0.0595000	380,731	0.1820000	0.1390000	0.1095000	0.0805000	0.0595000
471,861	0.1265000	0.0955000	0.0685000	0.0445000	0.0308000	471,861	0.1265000	0.0955000	0.0685000	0.0445000	0.0308000
584,804	0.0870000	0.0610000	0.0388000	0.0235000	0.0145000	584,804	0.0870000	0.0610000	0.0388000	0.0235000	0.0145000
724,780	0.0565000	0.0355000	0.0202000	0.0112000	0.0063000	724,780	0.0565000	0.0355000	0.0202000	0.0112000	0.0063000
898,260	0.0381000	0.0193000	0.0099000	0.0047000	0.0022000	898,260	0.0381000	0.0193000	0.0099000	0.0047000	0.0022000
1,113,264	0.0196000	0.0097000	0.0044000	0.0017000	0.0006350	1,113,264	0.0196000	0.0097000	0.0044000	0.0017000	0.0006350
1,379,730	0.0104200	0.0046000	0.0017000	0.0005650	0.0002400	1,379,730	0.0104200	0.0046000	0.0017000	0.0005650	0.0002400
1,709,976	0.0052250	0.0019700	0.0005950	0.0002220	0.0000600	1,709,976	0.0052250	0.0019700	0.0005950	0.0002220	0.0000600
2,119,269	0.0025450	0.0007550	0.0002600	0.0000750	0	2,119,269	0.0025450	0.0007550	0.0002600	0.0000750	0
2,626,528	0.0010800	0.0003380	0.0000850	0.0000230	0	2,626,528	0.0010800	0.0003380	0.0000850	0.0000230	0
3,255,202	0.0004520	0.0000950	0.0000500	0	0	3,255,202	0.0004520	0.0000950	0.0000500	0	0
4,034,354	0.0002150	0.0000620	0.0000090	0	0	4,034,354	0.0002150	0.0000620	0.0000090	0	0
5,000,000	0.0000830	0.0000210	0	0	0	5,000,000	0.0000830	0.0000210	0	0	0
			Climate Scenario: Sresa2-gfdl						**Climate Scenario: Sresa2-ncar**		
Year 2100						**Year 2100**					
200,000	0.4160000	0.3635000	0.3015000	0.2480000	0.1970000	200,000	0.5650000	0.5530000	0.4970000	0.4620000	0.4760000
247,871	0.3520000	0.2910000	0.2190000	0.1625000	0.1300000	247,871	0.5170000	0.4880000	0.4230000	0.3830000	0.3770000
307,201	0.2765000	0.2130000	0.1540000	0.1250000	0.0960000	307,201	0.4570000	0.4100000	0.3350000	0.2810000	0.2300000
380,731	0.2055000	0.1595000	0.1200000	0.0950000	0.0680000	380,731	0.3780000	0.3130000	0.2350000	0.1950000	0.1610000
471,861	0.1565000	0.1290000	0.0899000	0.0635000	0.0480000	471,861	0.2600000	0.2130000	0.1720000	0.1380000	0.0950000
584,804	0.1190000	0.0909000	0.0635000	0.0465000	0.0320000	584,804	0.1690000	0.1595000	0.1120000	0.0900000	0.0650000
724,780	0.0940000	0.0643000	0.0478000	0.0317000	0.0197000	724,780	0.1405000	0.1135000	0.0790000	0.0540000	0.0350000
898,260	0.0683000	0.0508000	0.0335000	0.0197000	0.0107000	898,260	0.1175000	0.0740000	0.0470000	0.0290000	0.0165000
1,113,264	0.0540000	0.0373000	0.0219000	0.0110000	0.0050500	1,113,264	0.0708000	0.0455000	0.0267000	0.0132000	0.0070000
1,379,730	0.0420000	0.0258000	0.0127000	0.0054000	0.0024500	1,379,730	0.0466000	0.0264000	0.0122000	0.0056000	0.0030000
1,709,976	0.0310000	0.0163000	0.0066500	0.0021000	0.0007030	1,709,976	0.0276000	0.0131000	0.0050900	0.0027000	0.0010000
2,119,269	0.0212000	0.0090300	0.0036500	0.0008300	0.0001730	2,119,269	0.0158000	0.0065000	0.0029500	0.0009500	0.0004000
2,626,528	0.0132000	0.0052000	0.0012100	0.0002230	0.0000140	2,626,528	0.0076100	0.0034500	0.0010000	0.0005200	0.0000000
3,255,202	0.0076500	0.0024700	0.0002920	0.0000163	0	3,255,202	0.0040700	0.0011700	0.0005900	0.0001300	0
4,034,354	0.0043000	0.0006850	0.0000300	0	0	4,034,354	0.0020000	0.0006700	0.0002000	0	0
5,000,000	0.0016600	0.0002200	0.0000080	0	0	5,000,000	0.0008200	0.0002900	0.0000000	0	0
Year 2050						**Year 2050**					
200,000	0.4930000	0.4595000	0.4150000	0.3730000	0.3245000	200,000	0.5410000	0.4850000	0.4520000	0.3970000	0.3120000
247,871	0.4263000	0.3830000	0.3410000	0.2815000	0.2325000	247,871	0.4550000	0.3930000	0.3470000	0.2900000	0.2090000
307,201	0.3440000	0.2950000	0.2370000	0.1895000	0.1460000	307,201	0.3500000	0.2910000	0.2390000	0.1850000	0.1450000
380,731	0.2610000	0.2095000	0.1605000	0.1205000	0.0950000	380,731	0.2480000	0.1980000	0.1470000	0.1080000	0.0880000
471,861	0.1825000	0.1365000	0.1075000	0.0782000	0.0595000	471,861	0.1670000	0.1240000	0.0900000	0.0645000	0.0480000
584,804	0.1240000	0.0953000	0.0698000	0.0488000	0.0337000	584,804	0.1075000	0.0795000	0.0630000	0.0340000	0.0225000
724,780	0.0843000	0.0655000	0.0450000	0.0285000	0.0172000	724,780	0.0722000	0.0460000	0.0273000	0.0165000	0.0085000
898,260	0.0632000	0.0437000	0.0267000	0.0147000	0.0078000	898,260	0.0410000	0.0240000	0.0132000	0.0061000	0.0030000
1,113,264	0.0445000	0.0270000	0.0145000	0.0067500	0.0029000	1,113,264	0.0221000	0.0117000	0.0053000	0.0022000	0.0009000
1,379,730	0.0291000	0.0157000	0.0068000	0.0027000	0.0012200	1,379,730	0.0112000	0.0051000	0.0020000	0.0006300	0.0003500
1,709,976	0.0177000	0.0080000	0.0028200	0.0011000	0.0004100	1,709,976	0.0052500	0.0021200	0.0009000	0.0002800	0.0000400
2,119,269	0.0102000	0.0035000	0.0013200	0.0004800	0.0000510	2,119,269	0.0023800	0.0009000	0.0002500	0.0000300	0.0000150
2,626,528	0.0050000	0.0017000	0.0005600	0.0000710	0	2,626,528	0.0009500	0.0003500	0.0000300	0.0000100	0
3,255,202	0.0022900	0.0007700	0.0000800	0.0000100	0	3,255,202	0.0005000	0.0000600	0.0000000	0.0000000	0
4,034,354	0.0011400	0.0002650	0.0000230	0	0	4,034,354	0.0001100	0.0000280	0.0000000	0	0
5,000,000	0.0004680	0.0000500	0.0000014	0	0	5,000,000	0.0000280	0.0000100	0.0000000	0	0
Year 2000						**Year 2000**					
200,000	0.4950000	0.4030000	0.3530000	0.2990000	0.2470000	200,000	0.4950000	0.4030000	0.3530000	0.2990000	0.2470000
247,871	0.3650000	0.3100000	0.2510000	0.1970000	0.1550000	247,871	0.3650000	0.3100000	0.2510000	0.1970000	0.1550000
307,201	0.2572000	0.2100000	0.1620000	0.1270000	0.1028000	307,201	0.2572000	0.2100000	0.1620000	0.1270000	0.1028000
380,731	0.1820000	0.1390000	0.1095000	0.0805000	0.0595000	380,731	0.1820000	0.1390000	0.1095000	0.0805000	0.0595000
471,861	0.1265000	0.0955000	0.0685000	0.0445000	0.0308000	471,861	0.1265000	0.0955000	0.0685000	0.0445000	0.0308000
584,804	0.0870000	0.0610000	0.0388000	0.0235000	0.0145000	584,804	0.0870000	0.0610000	0.0388000	0.0235000	0.0145000
724,780	0.0565000	0.0355000	0.0202000	0.0112000	0.0063000	724,780	0.0565000	0.0355000	0.0202000	0.0112000	0.0063000
898,260	0.0381000	0.0193000	0.0099000	0.0047000	0.0022000	898,260	0.0381000	0.0193000	0.0099000	0.0047000	0.0022000
1,113,264	0.0196000	0.0097000	0.0044000	0.0017000	0.0006350	1,113,264	0.0196000	0.0097000	0.0044000	0.0017000	0.0006350
1,379,730	0.0104200	0.0046000	0.0017000	0.0005650	0.0002400	1,379,730	0.0104200	0.0046000	0.0017000	0.0005650	0.0002400
1,709,976	0.0052250	0.0019700	0.0005950	0.0002220	0.0000600	1,709,976	0.0052250	0.0019700	0.0005950	0.0002220	0.0000600
2,119,269	0.0025450	0.0007550	0.0002600	0.0000750	0	2,119,269	0.0025450	0.0007550	0.0002600	0.0000750	0
2,626,528	0.0010800	0.0003380	0.0000850	0.0000230	0	2,626,528	0.0010800	0.0003380	0.0000850	0.0000230	0
3,255,202	0.0004520	0.0000950	0.0000500	0	0	3,255,202	0.0004520	0.0000950	0.0000500	0	0
4,034,354	0.0002150	0.0000620	0.0000090	0	0	4,034,354	0.0002150	0.0000620	0.0000090	0	0
5,000,000	0.0000830	0.0000210	0	0	0	5,000,000	0.0000830	0.0000210	0	0	0

Table 6-5: Annual Probability of Occurrence

Bin Number	Mean Bin Inflow	Probability of Occurrence, CL = 95%	Probability of Occurrence, CL = 80%	Probability of Occurrence, CL = 50%	Probability of Occurrence, CL = 20%	Probability of Occurrence, CL = 5%
Climate Scenario: Sresb1-gfdl						
Year 2100						
1	223,936	0.0650000	0.0790000	0.0990000	0.0900000	0.0860000
2	277,536	0.0790000	0.0840000	0.0860000	0.0620000	0.0470000
3	343,966	0.0800000	0.0780000	0.0595000	0.0440000	0.0415000
4	426,296	0.0640000	0.0575000	0.0405000	0.0365000	0.0307000
5	528,332	0.0470000	0.0270000	0.0275000	0.0335000	0.0208000
6	654,792	0.0280000	0.0315000	0.0230000	0.0170000	0.0137000
7	811,520	0.0205000	0.0230000	0.0175000	0.0112000	0.0070000
8	1,005,762	0.0314000	0.0165000	0.0093000	0.0063000	0.0045000
9	1,246,497	0.0134000	0.0079000	0.0074000	0.0039000	0.0014000
10	1,544,853	0.0087000	0.0069000	0.0031000	0.0013000	0.0007000
11	1,914,622	0.0068000	0.0039500	0.0016700	0.0006000	0.0004200
12	2,372,898	0.0042000	0.0018300	0.0008500	0.0003700	0.0002800
13	2,940,865	0.0022200	0.0011000	0.0003500	0.0003300	0.0000000
14	3,644,778	0.0014300	0.0004200	0.0003300	0.0000000	0.0000000
15	4,517,177	0.0007900	0.0003300	0.0000000	0.0000000	0.0000000
Year 2050						
1	223,936	0.0700000	0.0840000	0.0980000	0.0930000	0.0880000
2	277,536	0.0860000	0.0920000	0.0845000	0.0685000	0.0510000
3	343,966	0.0810000	0.0690000	0.0493000	0.0480000	0.0410000
4	426,296	0.0560000	0.0455000	0.0407000	0.0353000	0.0292000
5	528,332	0.0420000	0.0305000	0.0300000	0.0222000	0.0193000
6	654,792	0.0320000	0.0322000	0.0253000	0.0155000	0.0122000
7	811,520	0.0250000	0.0188000	0.0119000	0.0095000	0.0048000
8	1,005,762	0.0177000	0.0123000	0.0083000	0.0045000	0.0030000
9	1,246,497	0.0127000	0.0082500	0.0044000	0.0021200	0.0008000
10	1,544,853	0.0078000	0.0041000	0.0021000	0.0006800	0.0004000
11	1,914,622	0.0045000	0.0025000	0.0007000	0.0003500	0.0003000
12	2,372,898	0.0026500	0.0009200	0.0004000	0.0003500	0.0000000
13	2,940,865	0.0014600	0.0004000	0.0003300	0.0000000	0.0000000
14	3,644,778	0.0004900	0.0004000	0.0000700	0.0000000	0.0000000
15	4,517,177	0.0003500	0.0001300	0.0000000	0.0000000	0.0000000
Year 2000						
1	223,936	0.1300000	0.0930000	0.1020000	0.1020000	0.0920000
2	277,536	0.1078000	0.1000000	0.0890000	0.0700000	0.0522000
3	343,966	0.0752000	0.0710000	0.0525000	0.0465000	0.0433000
4	426,296	0.0555000	0.0435000	0.0410000	0.0360000	0.0287000
5	528,332	0.0395000	0.0345000	0.0297000	0.0210000	0.0163000
6	654,792	0.0305000	0.0255000	0.0186000	0.0123000	0.0082000
7	811,520	0.0184000	0.0162000	0.0103000	0.0065000	0.0041000
8	1,005,762	0.0185000	0.0096000	0.0055000	0.0030000	0.0015650
9	1,246,497	0.0091800	0.0051000	0.0027000	0.0011350	0.0003950
10	1,544,853	0.0051950	0.0026300	0.0011050	0.0003430	0.0001800
11	1,914,622	0.0026800	0.0012150	0.0003350	0.0001470	0.0000600
12	2,372,898	0.0014650	0.0004170	0.0001750	0.0000520	0.0000000
13	2,940,865	0.0006280	0.0002430	0.0000350	0.0000230	0.0000000
14	3,644,778	0.0002370	0.0000330	0.0000410	0.0000000	0.0000000
15	4,517,177	0.0001320	0.0000410	0.0000090	0.0000000	0.0000000
Climate Scenario: Sresa2-gfdl						
Year 2100						
1	223,936	0.0640000	0.0725000	0.0825000	0.0855000	0.0670000
2	277,536	0.0755000	0.0780000	0.0650000	0.0375000	0.0340000
3	343,966	0.0710000	0.0535000	0.0340000	0.0300000	0.0280000
4	426,296	0.0490000	0.0305000	0.0301000	0.0315000	0.0200000
5	528,332	0.0375000	0.0381000	0.0264000	0.0170000	0.0160000
6	654,792	0.0250000	0.0266000	0.0157000	0.0148000	0.0123000
7	811,520	0.0257000	0.0135000	0.0143000	0.0120000	0.0090000
8	1,005,762	0.0143000	0.0135000	0.0116000	0.0087000	0.0056500
9	1,246,497	0.0120000	0.0115000	0.0092000	0.0056000	0.0026000
10	1,544,853	0.0110000	0.0095000	0.0060500	0.0033000	0.0017470
11	1,914,622	0.0098000	0.0072700	0.0030000	0.0012700	0.0005300
12	2,372,898	0.0080000	0.0038300	0.0024400	0.0006070	0.0001590
13	2,940,865	0.0055500	0.0027300	0.0009180	0.0002067	0.0000140
14	3,644,778	0.0033500	0.0017850	0.0002620	0.0000163	0.0000000
15	4,517,177	0.0026400	0.0004650	0.0000221	0.0000000	0.0000000
Year 2050						
1	223,936	0.0667000	0.0765000	0.0740000	0.0915000	0.0920000
2	277,536	0.0823000	0.0880000	0.1040000	0.0920000	0.0865000
3	343,966	0.0830000	0.0855000	0.0765000	0.0690000	0.0510000
4	426,296	0.0785000	0.0730000	0.0530000	0.0423000	0.0355000
5	528,332	0.0585000	0.0412000	0.0377000	0.0294000	0.0258000
6	654,792	0.0397000	0.0298000	0.0248000	0.0203000	0.0165000
7	811,520	0.0211000	0.0218000	0.0183000	0.0138000	0.0094000
8	1,005,762	0.0187000	0.0167000	0.0122000	0.0079500	0.0049000
9	1,246,497	0.0154000	0.0113000	0.0077000	0.0040500	0.0016800
10	1,544,853	0.0114000	0.0077000	0.0039800	0.0016000	0.0008100
11	1,914,622	0.0075000	0.0045000	0.0015000	0.0006200	0.0003590
12	2,372,898	0.0052000	0.0018000	0.0007600	0.0004090	0.0000510
13	2,940,865	0.0027100	0.0009300	0.0004800	0.0000610	0.0000000
14	3,644,778	0.0011500	0.0005050	0.0000570	0.0000100	0.0000000
15	4,517,177	0.0006720	0.0002150	0.0000216	0.0000000	0.0000000
Year 2000						
1	223,936	0.1300000	0.0930000	0.1020000	0.1020000	0.0920000
2	277,536	0.1078000	0.1000000	0.0890000	0.0700000	0.0522000
3	343,966	0.0752000	0.0710000	0.0525000	0.0465000	0.0433000
4	426,296	0.0555000	0.0435000	0.0410000	0.0360000	0.0287000
5	528,332	0.0395000	0.0345000	0.0297000	0.0210000	0.0163000
6	654,792	0.0305000	0.0255000	0.0186000	0.0123000	0.0082000
7	811,520	0.0184000	0.0162000	0.0103000	0.0065000	0.0041000
8	1,005,762	0.0185000	0.0096000	0.0055000	0.0030000	0.0015650
9	1,246,497	0.0091800	0.0051000	0.0027000	0.0011350	0.0003950
10	1,544,853	0.0051950	0.0026300	0.0011050	0.0003430	0.0001800
11	1,914,622	0.0026800	0.0012150	0.0003350	0.0001470	0.0000600
12	2,372,898	0.0014650	0.0004170	0.0001750	0.0000520	0.0000000
13	2,940,865	0.0006280	0.0002430	0.0000350	0.0000230	0.0000000
14	3,644,778	0.0002370	0.0000330	0.0000410	0.0000000	0.0000000
15	4,517,177	0.0001320	0.0000410	0.0000090	0.0000000	0.0000000

Bin Number	Mean Bin Inflow	Probability of Occurrence, CL = 95%	Probability of Occurrence, CL = 80%	Probability of Occurrence, CL = 50%	Probability of Occurrence, CL = 20%	Probability of Occurrence, CL = 5%
Climate Scenario: Sresb1-ncar						
Year 2100						
1	223,936	0.0460000	0.0380000	0.0510000	0.0490000	0.0560000
2	277,536	0.0540000	0.0470000	0.0500000	0.0540000	0.0640000
3	343,966	0.0580000	0.0480000	0.0470000	0.0740000	0.1350000
4	426,296	0.0440000	0.0570000	0.0850000	0.1030000	0.0250000
5	528,332	0.0580000	0.0840000	0.0970000	0.0610000	0.0480000
6	654,792	0.0850000	0.0780000	0.0510000	0.0400000	0.0400000
7	811,520	0.0640000	0.0580000	0.0440000	0.0390000	0.0390000
8	1,005,762	0.0560000	0.0280000	0.0280000	0.0345000	0.0260000
9	1,246,497	0.0410000	0.0330000	0.0323000	0.0195000	0.0150000
10	1,544,853	0.0233000	0.0363000	0.0202000	0.0130000	0.0145000
11	1,914,622	0.0312000	0.0192000	0.0140000	0.0170000	0.0083000
12	2,372,898	0.0172000	0.0132000	0.0120000	0.0075000	0.0039000
13	2,940,865	0.0163000	0.0083000	0.0080000	0.0038000	0.0003000
14	3,644,778	0.0097000	0.0074000	0.0046000	0.0017000	0.0000000
15	4,517,177	0.0101100	0.0076000	0.0034700	0.0000000	0.0000000
Year 2050						
1	223,936	0.0510000	0.0640000	0.0705000	0.0800000	0.0840000
2	277,536	0.0620000	0.0740000	0.0795000	0.0840000	0.0850000
3	343,966	0.0700000	0.0790000	0.0840000	0.0760000	0.0710000
4	426,296	0.0770000	0.0750000	0.0670000	0.0760000	0.0480000
5	528,332	0.0710000	0.0670000	0.0520000	0.0240000	0.0370000
6	654,792	0.0585000	0.0440000	0.0380000	0.0335000	0.0290000
7	811,520	0.0365000	0.0345000	0.0290000	0.0250000	0.0190000
8	1,005,762	0.0345000	0.0255000	0.0230000	0.0163000	0.0117000
9	1,246,497	0.0222000	0.0210000	0.0155000	0.0112000	0.0061000
10	1,544,853	0.0213000	0.0142000	0.0092000	0.0042000	0.0046000
11	1,914,622	0.0149000	0.0090000	0.0050000	0.0041000	0.0022300
12	2,372,898	0.0087000	0.0055800	0.0036000	0.0022400	0.0003700
13	2,940,865	0.0067500	0.0038700	0.0025000	0.0004600	0.0000000
14	3,644,778	0.0036500	0.0020500	0.0009200	0.0000000	0.0000000
15	4,517,177	0.0027000	0.0017400	0.0002800	0.0000000	0.0000000
Year 2000						
1	223,936	0.1300000	0.0930000	0.1020000	0.1020000	0.0920000
2	277,536	0.1078000	0.1000000	0.0890000	0.0700000	0.0522000
3	343,966	0.0752000	0.0710000	0.0525000	0.0465000	0.0433000
4	426,296	0.0555000	0.0435000	0.0410000	0.0360000	0.0287000
5	528,332	0.0395000	0.0345000	0.0297000	0.0210000	0.0163000
6	654,792	0.0305000	0.0255000	0.0186000	0.0123000	0.0082000
7	811,520	0.0184000	0.0162000	0.0103000	0.0065000	0.0041000
8	1,005,762	0.0185000	0.0096000	0.0055000	0.0030000	0.0015650
9	1,246,497	0.0091800	0.0051000	0.0027000	0.0011350	0.0003950
10	1,544,853	0.0051950	0.0026300	0.0011050	0.0003430	0.0001800
11	1,914,622	0.0026800	0.0012150	0.0003350	0.0001470	0.0000600
12	2,372,898	0.0014650	0.0004170	0.0001750	0.0000520	0.0000000
13	2,940,865	0.0006280	0.0002430	0.0000350	0.0000230	0.0000000
14	3,644,778	0.0002370	0.0000330	0.0000410	0.0000000	0.0000000
15	4,517,177	0.0001320	0.0000410	0.0000090	0.0000000	0.0000000
Climate Scenario: Sresa2-ncar						
Year 2100						
1	223,936	0.0480000	0.0650000	0.0740000	0.0790000	0.0990000
2	277,536	0.0600000	0.0780000	0.0880000	0.1020000	0.1470000
3	343,966	0.0790000	0.0970000	0.1000000	0.0860000	0.0690000
4	426,296	0.1180000	0.1000000	0.0630000	0.0570000	0.0660000
5	528,332	0.0910000	0.0535000	0.0600000	0.0480000	0.0300000
6	654,792	0.0285000	0.0460000	0.0330000	0.0360000	0.0300000
7	811,520	0.0230000	0.0395000	0.0320000	0.0250000	0.0185000
8	1,005,762	0.0467000	0.0285000	0.0203000	0.0158000	0.0095000
9	1,246,497	0.0242000	0.0191000	0.0145000	0.0076000	0.0040000
10	1,544,853	0.0190000	0.0133000	0.0071100	0.0029000	0.0020000
11	1,914,622	0.0118000	0.0066000	0.0021400	0.0017500	0.0006000
12	2,372,898	0.0081900	0.0030500	0.0019500	0.0004300	0.0004000
13	2,940,865	0.0035400	0.0022800	0.0004100	0.0003900	0.0000000
14	3,644,778	0.0020700	0.0005000	0.0003900	0.0001300	0.0000000
15	4,517,177	0.0011800	0.0003800	0.0002000	0.0000000	0.0000000
Year 2050						
1	223,936	0.0860000	0.0920000	0.1050000	0.1070000	0.1030000
2	277,536	0.1050000	0.1020000	0.1080000	0.1050000	0.0640000
3	343,966	0.1020000	0.0930000	0.0920000	0.0770000	0.0570000
4	426,296	0.0810000	0.0740000	0.0570000	0.0435000	0.0400000
5	528,332	0.0595000	0.0445000	0.0270000	0.0305000	0.0255000
6	654,792	0.0353000	0.0335000	0.0357000	0.0175000	0.0140000
7	811,520	0.0312000	0.0220000	0.0141000	0.0104000	0.0055000
8	1,005,762	0.0189000	0.0123000	0.0079000	0.0039000	0.0021000
9	1,246,497	0.0109000	0.0066000	0.0033000	0.0015700	0.0005500
10	1,544,853	0.0059500	0.0029800	0.0011000	0.0003500	0.0003100
11	1,914,622	0.0028700	0.0012200	0.0006500	0.0002500	0.0000250
12	2,372,898	0.0014300	0.0005500	0.0002200	0.0000200	0.0000150
13	2,940,865	0.0004500	0.0002900	0.0000300	0.0000100	0.0000000
14	3,644,778	0.0003900	0.0000320	0.0000000	0.0000000	0.0000000
15	4,517,177	0.0000820	0.0000180	0.0000000	0.0000000	0.0000000
Year 2000						
1	223,936	0.1300000	0.0930000	0.1020000	0.1020000	0.0920000
2	277,536	0.1078000	0.1000000	0.0890000	0.0700000	0.0522000
3	343,966	0.0752000	0.0710000	0.0525000	0.0465000	0.0433000
4	426,296	0.0555000	0.0435000	0.0410000	0.0360000	0.0287000
5	528,332	0.0395000	0.0345000	0.0297000	0.0210000	0.0163000
6	654,792	0.0305000	0.0255000	0.0186000	0.0123000	0.0082000
7	811,520	0.0184000	0.0162000	0.0103000	0.0065000	0.0041000
8	1,005,762	0.0185000	0.0096000	0.0055000	0.0030000	0.0015650
9	1,246,497	0.0091800	0.0051000	0.0027000	0.0011350	0.0003950
10	1,544,853	0.0051950	0.0026300	0.0011050	0.0003430	0.0001800
11	1,914,622	0.0026800	0.0012150	0.0003350	0.0001470	0.0000600
12	2,372,898	0.0014650	0.0004170	0.0001750	0.0000520	0.0000000
13	2,940,865	0.0006280	0.0002430	0.0000350	0.0000230	0.0000000
14	3,644,778	0.0002370	0.0000330	0.0000410	0.0000000	0.0000000
15	4,517,177	0.0001320	0.0000410	0.0000090	0.0000000	0.0000000

Table 6-6: Probability of Occurrence of a Hydrologic Event in Future Years

Year & Confidence Limit	Probability of Hydrologic Event Being in Bin(I) Where Value & Range of Bin(I) Is Given in Table 6-3							
	P = EXP[A x (QBin(I))2 + B x QBin(I) + C]			Statistical Fit, R2	P = EXP[A x (QBin(I))2 + B x QBin(I) + C]			Statistical Fit, R2
	A	B	C		A	B	C	
	Climate Change Scenario: Sresa2-gfdl				**Climate Change Scenario: Sresb1-gfdl**			
YEAR 2100								
95%	1.78476E-13	-1.54174E-06	-2.45948E+00	0.954	1.61899E-13	-1.81732E-06	-2.16653E+00	0.983
80%	9.40487E-14	-1.47456E-06	-2.59966E+00	0.959	2.22203E-13	-2.34454E-06	-1.99705E+00	0.991
50%	-8.61129E-14	-1.27142E-06	-2.84093E+00	0.977	4.11893E-13	-3.24743E-06	-1.74278E+00	0.995
20%	-1.11187E-13	-1.77505E-06	-2.75602E+00	0.985	7.01287E-13	-4.30825E-06	-1.53260E+00	0.994
5%	-2.29969E-13	-2.10062E-06	-2.77384E+00	0.991	9.63317E-13	-5.13977E-06	-1.46740E+00	0.995
YEAR 2050								
95%	1.26113E-13	-1.70656E-06	-2.13124E+00	0.984	1.65796E-13	-2.07067E-06	-2.04619E+00	0.995
80%	1.78997E-13	-2.23475E-06	-1.93723E+00	0.995	2.68099E-13	-2.73858E-06	-1.86383E+00	0.992
50%	1.28388E-13	-2.53767E-06	-1.90043E+00	0.992	5.99412E-13	-4.02947E-06	-1.48611E+00	0.994
20%	1.29527E-13	-3.09148E-06	-1.78396E+00	0.994	1.00562E-12	-5.30410E-06	-1.23012E+00	0.994
5%	2.42737E-13	-3.99668E-06	-1.56217E+00	0.995	1.26223E-12	-6.12977E-06	-1.16462E+00	0.992
YEAR 2000								
95%	2.32680E-13	-2.64473E-06	-1.71365E+00	0.995	2.32680E-13	-2.64473E-06	-1.71365E+00	0.995
80%	3.06446E-13	-3.32274E-06	-1.60018E+00	0.992	3.06446E-13	-3.32274E-06	-1.60018E+00	0.992
50%	4.26509E-13	-4.10926E-06	-1.47391E+00	0.994	4.26509E-13	-4.10926E-06	-1.47391E+00	0.994
20%	7.62514E-13	-5.48314E-06	-1.15630E+00	0.999	7.62514E-13	-5.48314E-06	-1.15630E+00	0.999
5%	9.92779E-13	-6.46388E-06	-1.03537E+00	0.997	9.92779E-13	-6.46388E-06	-1.03537E+00	0.997
	Climate Change Scenario: Sresa2-ncar				**Climate Change Scenario: Sresb1-ncar**			
YEAR 2100								
95%	4.51000E-14	-1.21140E-06	-2.28293E+00	0.936	1.65208E-14	-5.52666E-07	-2.61984E+00	0.863
80%	8.98985E-14	-1.76614E-06	-1.93062E+00	0.985	5.17210E-14	-7.97334E-07	-2.55874E+00	0.853
50%	2.37332E-13	-2.60945E-06	-1.64407E+00	0.986	5.49444E-14	-9.77816E-07	-2.44362E+00	0.938
20%	3.08201E-13	-3.16795E-06	-1.48842E+00	0.991	-2.67606E-14	-9.83750E-07	-2.42673E+00	0.952
5%	5.18293E-13	-4.09703E-06	-1.17241E+00	0.989	-5.13061E-13	-1.82185E-07	-2.77567E+00	0.929
YEAR 2050								
95%	1.88201E-13	-2.53249E-06	-1.61596E+00	0.993	7.45379E-14	-1.14556E-06	-2.32689E+00	0.975
80%	2.06379E-13	-3.04519E-06	-1.50099E+00	0.994	1.54421E-13	-1.65575E-06	-2.08640E+00	0.991
50%	2.28947E-13	-3.68150E-06	-1.34734E+00	0.992	8.49741E-14	-1.68202E-06	-2.13604E+00	0.991
20%	4.66652E-13	-5.02163E-06	-9.71574E+01	0.993	1.02877E-13	-2.13890E-06	-2.02355E+00	0.968
5%	6.01678E-13	-5.84877E-06	-9.13610E+01	0.991	-5.21422E-14	-2.26041E-06	-1.98892E+00	0.987
YEAR 2000								
95%	2.32680E-13	-2.64473E-06	-1.71365E+00	0.995	2.32680E-13	-2.64473E-06	-1.71365E+00	0.995
80%	3.06446E-13	-3.32274E-06	-1.60018E+00	0.992	3.06446E-13	-3.32274E-06	-1.60018E+00	0.992
50%	4.26509E-13	-4.10926E-06	-1.47391E+00	0.994	4.26509E-13	-4.10926E-06	-1.47391E+00	0.994
20%	7.62514E-13	-5.48314E-06	-1.15630E+00	0.999	7.62514E-13	-5.48314E-06	-1.15630E+00	0.999
5%	9.92779E-13	-6.46388E-06	-1.03537E+00	0.997	9.92779E-13	-6.46388E-06	-1.03537E+00	0.997

Table 6-7: Future Changes in Delta Inflow Patterns, Climate Scenario Sresa2-gfdl

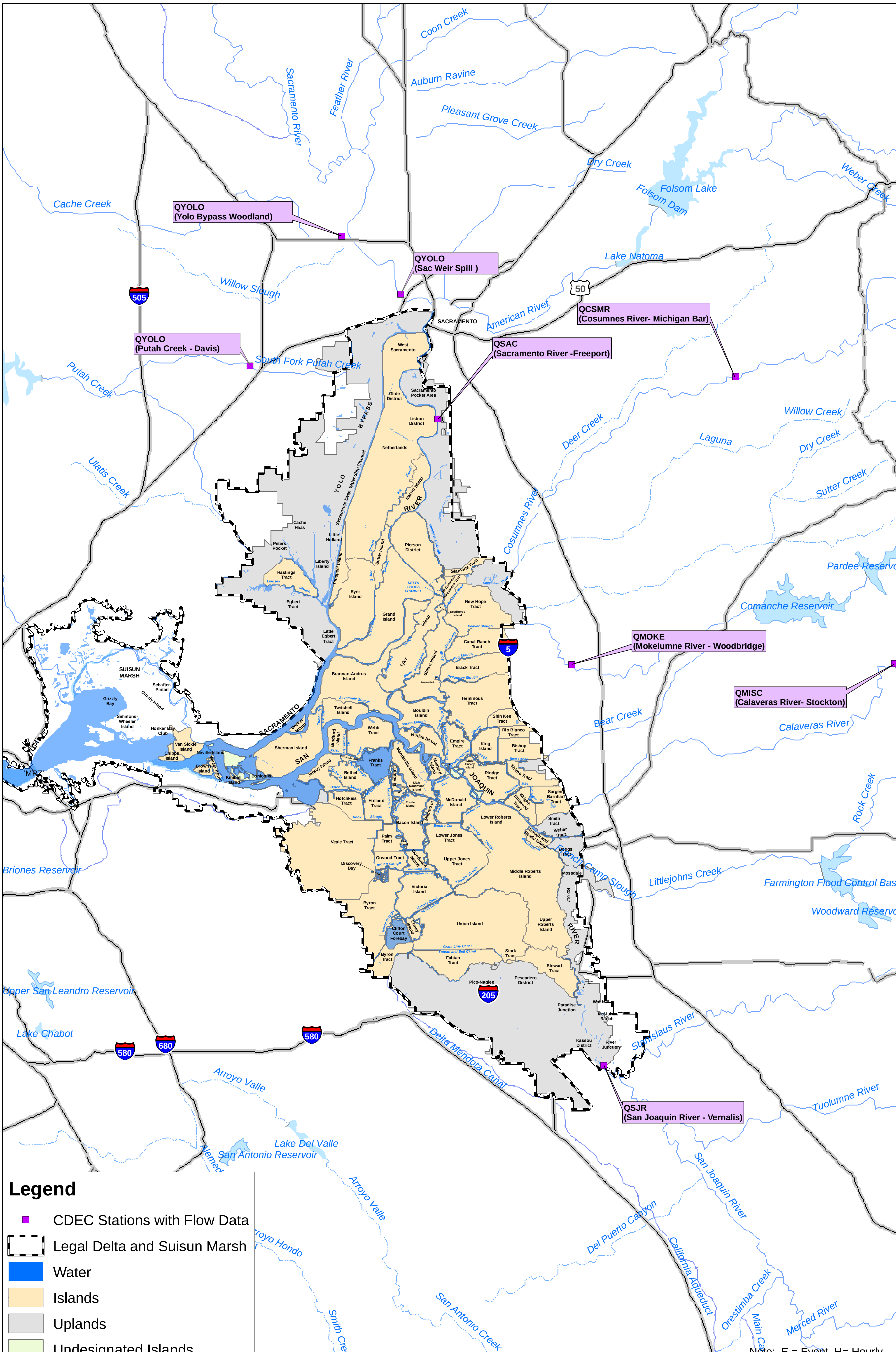
Watershed Runoff Location	Average Contribution to Annual Peaks, 1951-2000	Average Contribution to Annual Peaks, 2001-2050	Average Contribution to Annual Peaks, 2051-2100
Yuba R at Smartville	11.2%	12.4%	11.6%
Sacramento R at Shasta Dam	17.6%	15.8%	17.1%
Feather R at Oroville	11.0%	12.2%	12.6%
Calaveras R at New Hogan	1.6%	1.6%	1.4%
San Joaquin R at Millerton Lake	2.2%	2.6%	2.7%
American R at Folsom Dam	8.5%	8.9%	8.1%
Consumnes R at McConnell	3.0%	2.7%	2.3%
Bear Creek	0.9%	1.0%	0.9%
Butte Cr	0.6%	0.7%	0.6%
Tuolumne R at New Don Pedro	3.6%	4.1%	3.8%
Fresno R	0.1%	0.1%	0.1%
Kings R at Pine Flat Dam	1.7%	2.2%	2.3%
Merced R at Lake McClure	2.2%	3.0%	2.6%
March Cr	0.0%	0.0%	0.0%
Merced R at Pohono Br	0.1%	0.2%	0.2%
Stanislaus R at New Melones Dam	2.5%	2.9%	2.6%
NF American R at NF Dam	1.8%	2.1%	1.9%
Paynes Cr	0.2%	0.2%	0.2%
Mokelumne R at Pardee	2.6%	3.0%	2.5%
Sacramento R at Delta	2.6%	2.1%	2.6%
Stony Cr	0.5%	0.4%	0.4%
Thomes Cr	0.5%	0.3%	0.4%
Sacramento R at Bend Br.	24.8%	21.7%	23.2%
No. Annual Events Included In Period	**16**	**13**	**14**

Table 7-1: Measured Water Surface Elevations at VNI Station[1]

Water Year	Water Surface Elevation (NAVD 88), feet	Water Year	Water Surface Elevation (NAVD 88), feet
1945	7.60	1977	6.90
1946	7.70	1978	7.80
1947	7.40	1979	7.50
1948	7.20	1980	8.90
1949	7.10	1981	7.20
1950	7.40	1982	8.30
1951	8.80	1983	9.80
1953	8.30	1984	9.80
1954	7.50	1985	7.52
1955	7.50	1986	9.67
1956	9.80	1987	7.91
1957	7.30	1988	8.12
1958	9.30	1989	7.62
1959	7.70	1990	7.9
1960	7.70	1991	7.46
1961	7.10	1992	7.75
1962	7.90	1993	8.02
1963	8.10	1994	7.75
1964	7.20	1995	8.72
1965	8.60	1996	8.16
1966	7.50	1997	8.97
1967	8.60	1998	10.16
1968	7.40	1999	7.95
1969	8.90	2000	8.54
1970	8.70	2001	7.38
1971	7.80	2002	8.22
1972	7.30	2003	8.58
1973	9.30	2004	8.16
1974	7.90	2005	8.48
1975	7.60	2006	10.04
1976	6.90		

(1) Data for Water Years 1945 through 1984 from USACE (February 1992) and 1985 through 2006 from CDEC.

Figures

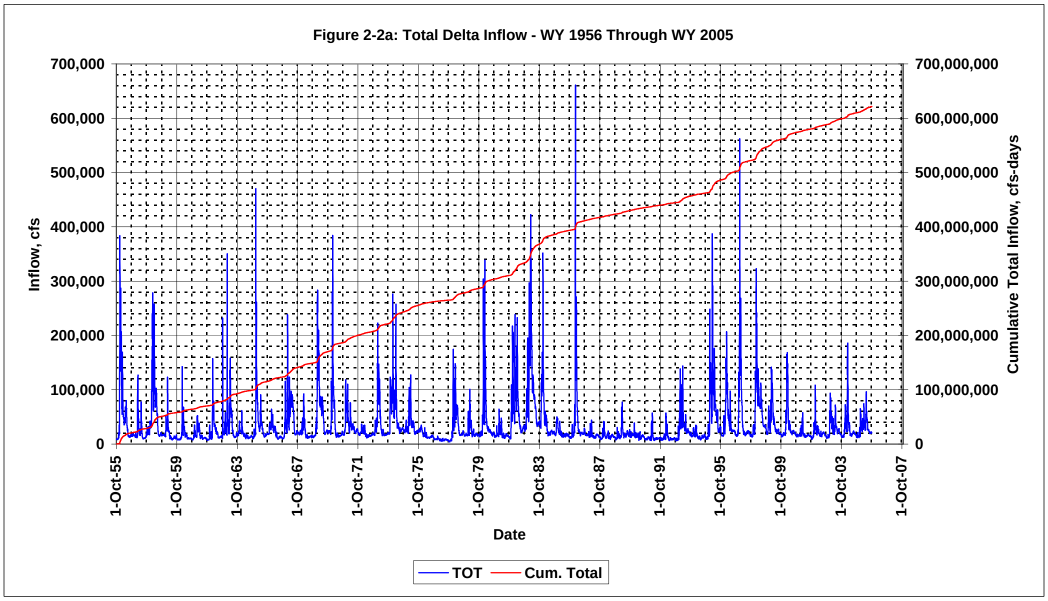


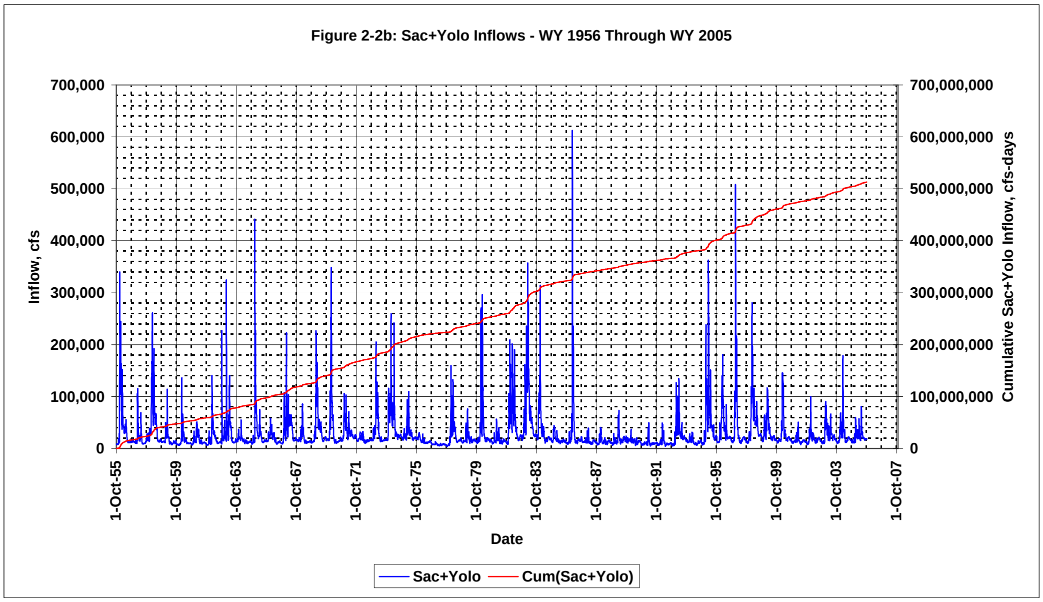
URS

DRMS	Flow Stations Used with Flood Hazard Analysis	Figure 2-1
26815431		

URS Corporation P:\GIS\GIS_Project_Files\OriginalData\Regional_Data\CDEC_stations\stations_with_flow_data.mxd Date: 12/11/2006 2:35:15 PM Name: smlewis0

FIGURE 2-2: HISTORICAL DELTA INFLOWS





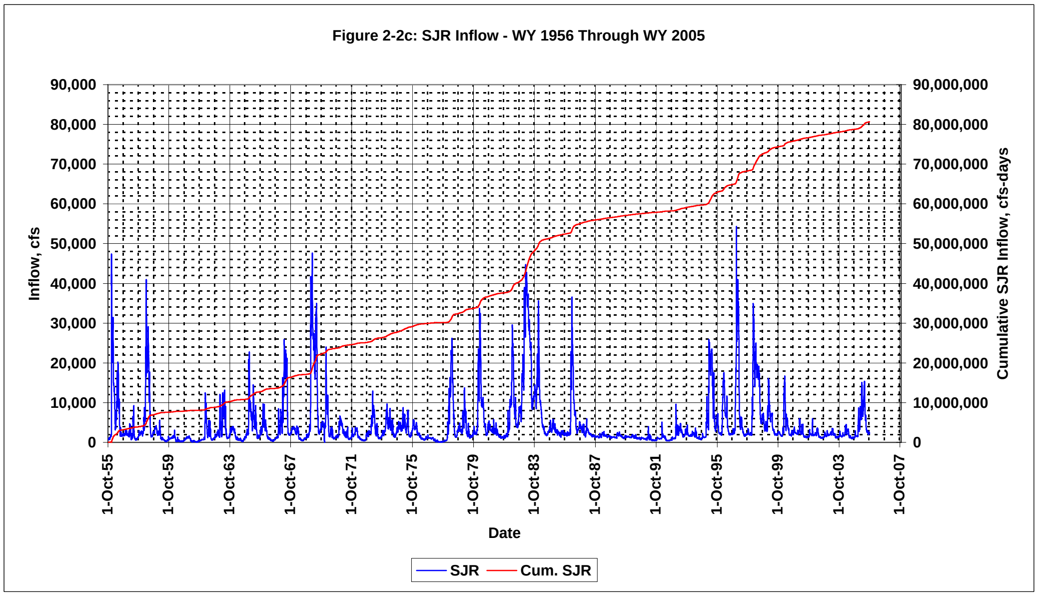
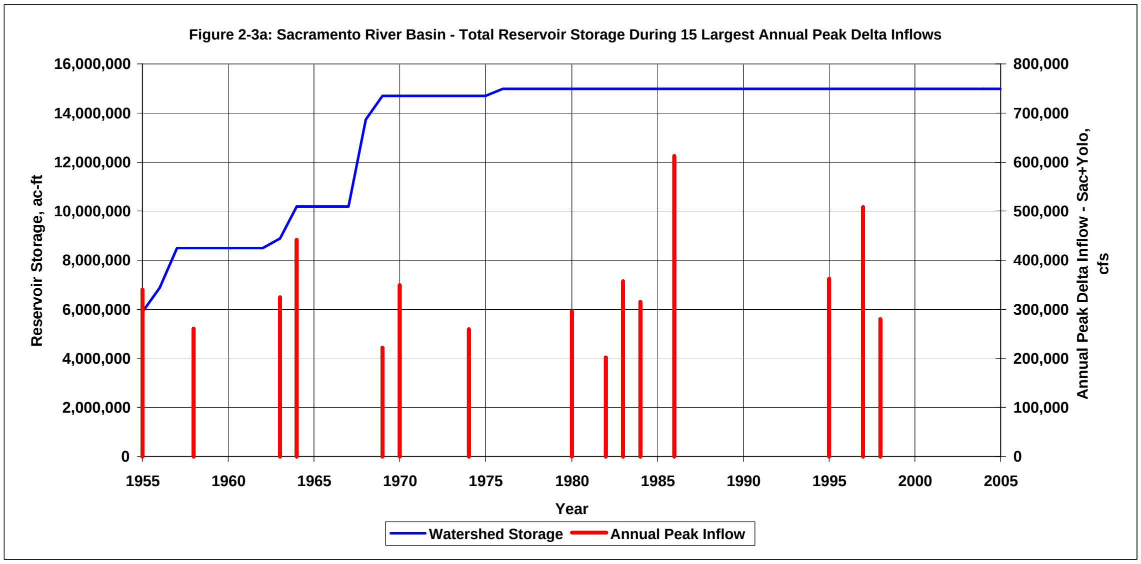
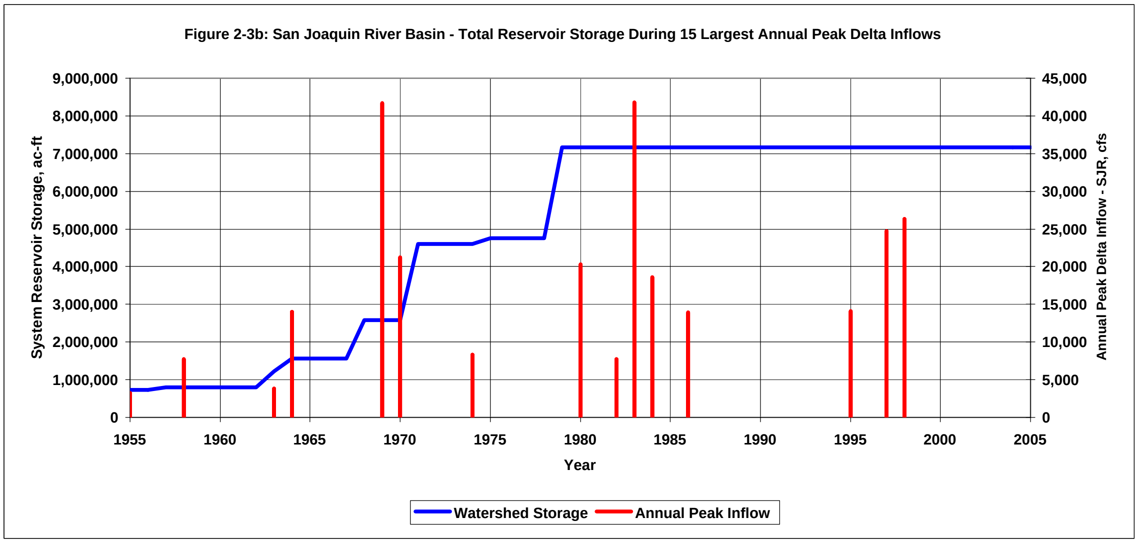


FIGURE 2-3: RESERVOIR STORAGE





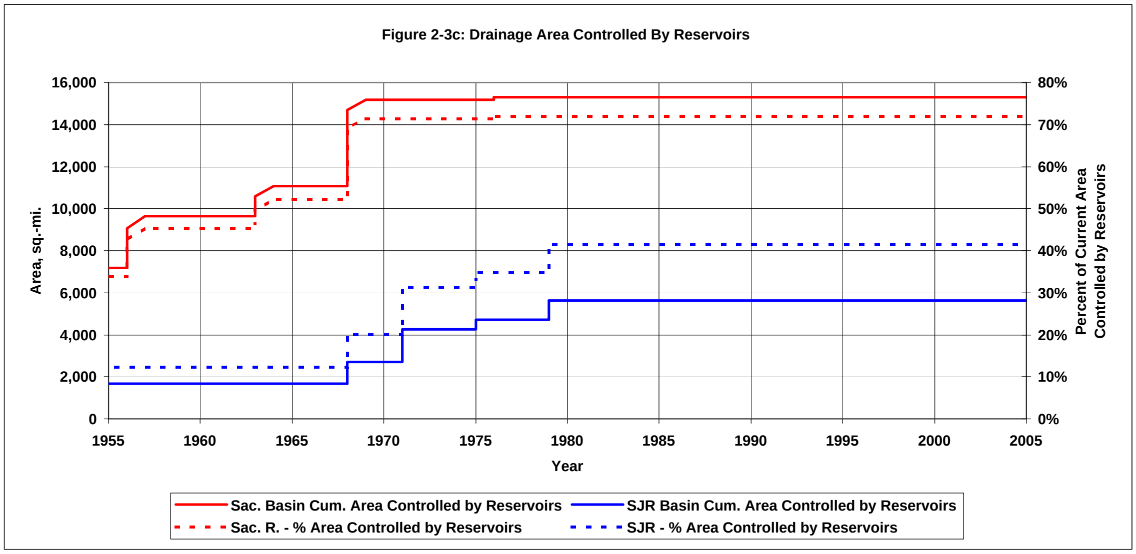
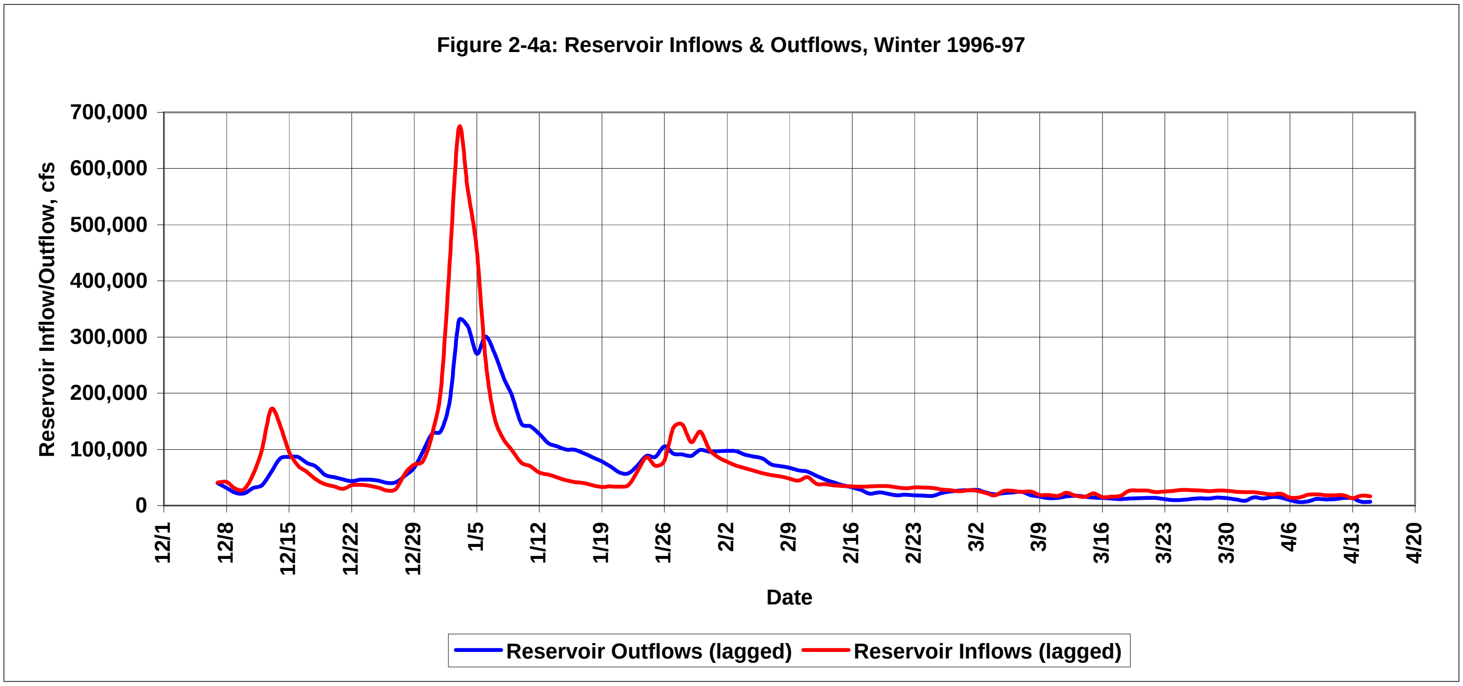


FIGURE 2-4: SACRAMENTO RIVER WATERSHED FLOWS



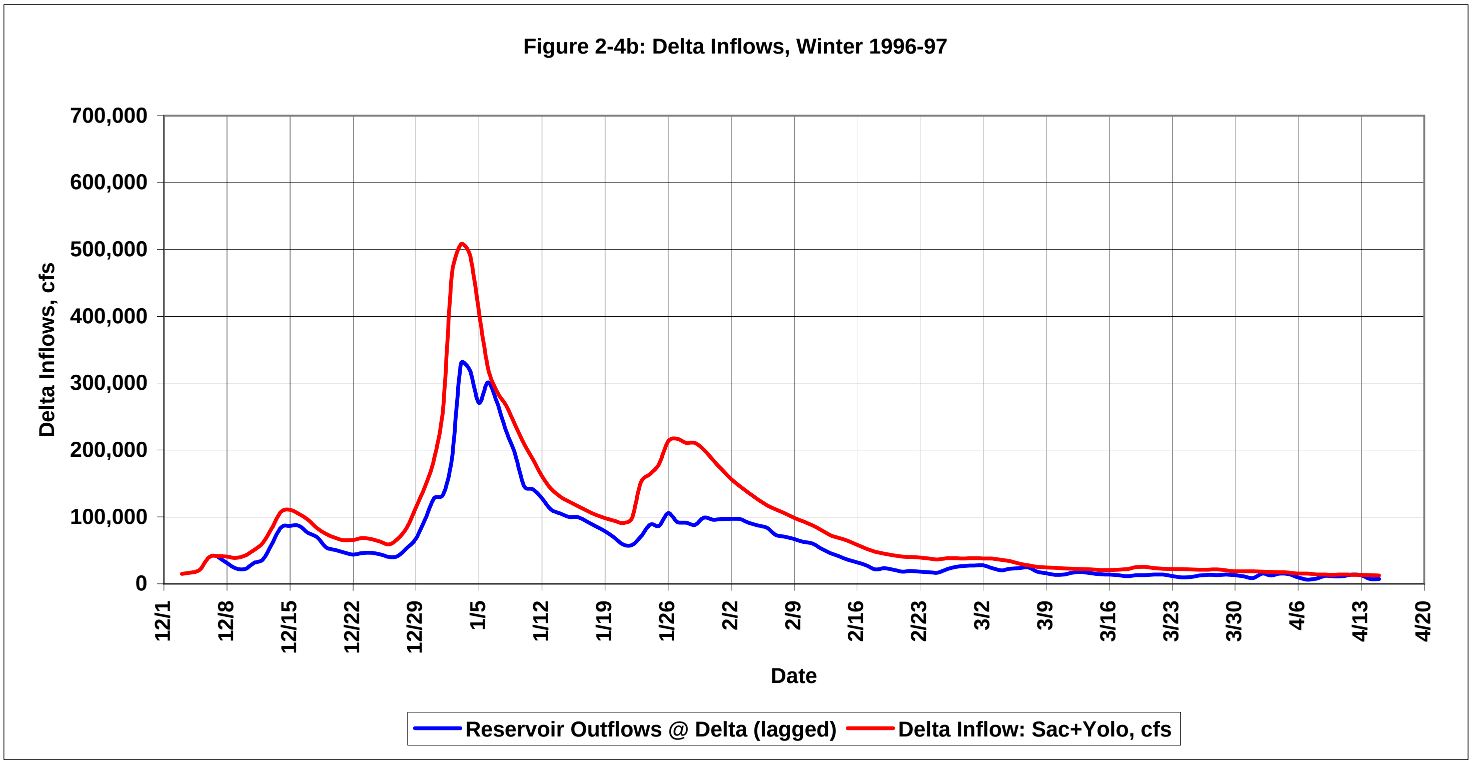


FIGURE 2-5: SAN JOAQUIN RIVER WATERSHED, WINTER 1997

Figure 2-5a: Reservoir Inflows and Outflows, Winter 1997

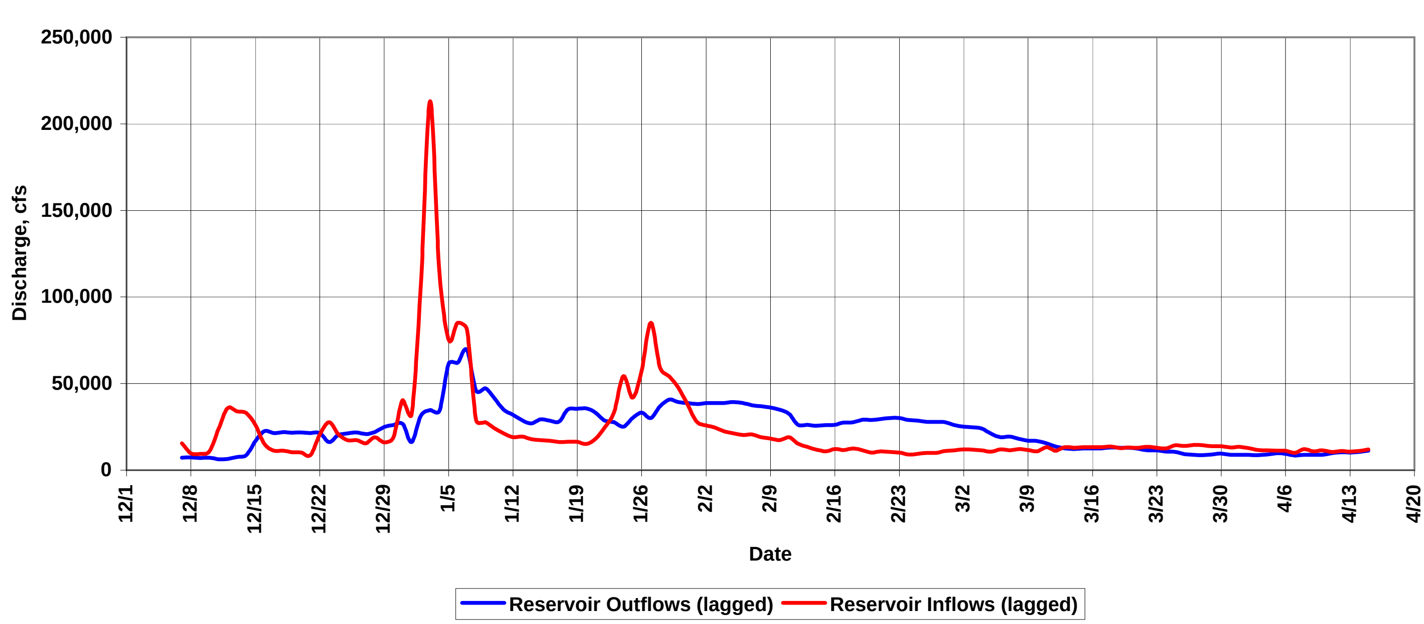


Figure 2-5b: Reservoir Outflow (lagged) and Delta Inflow, Winter 1997

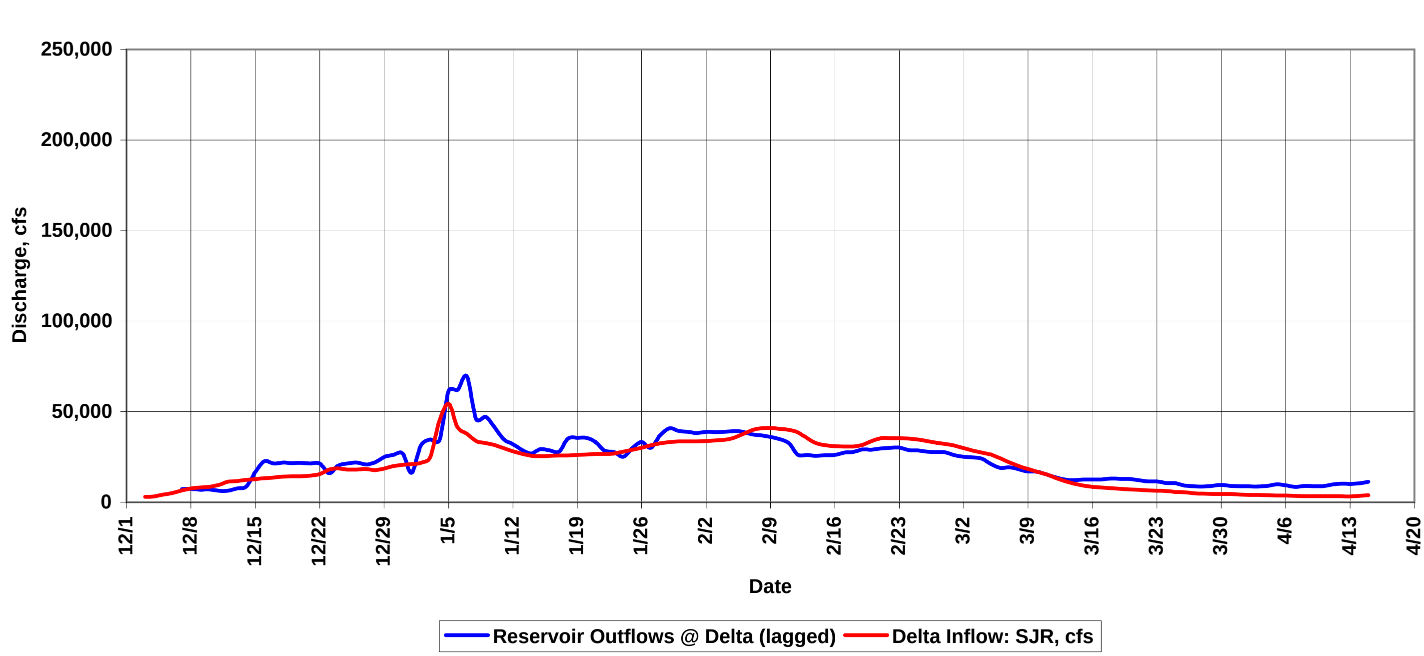
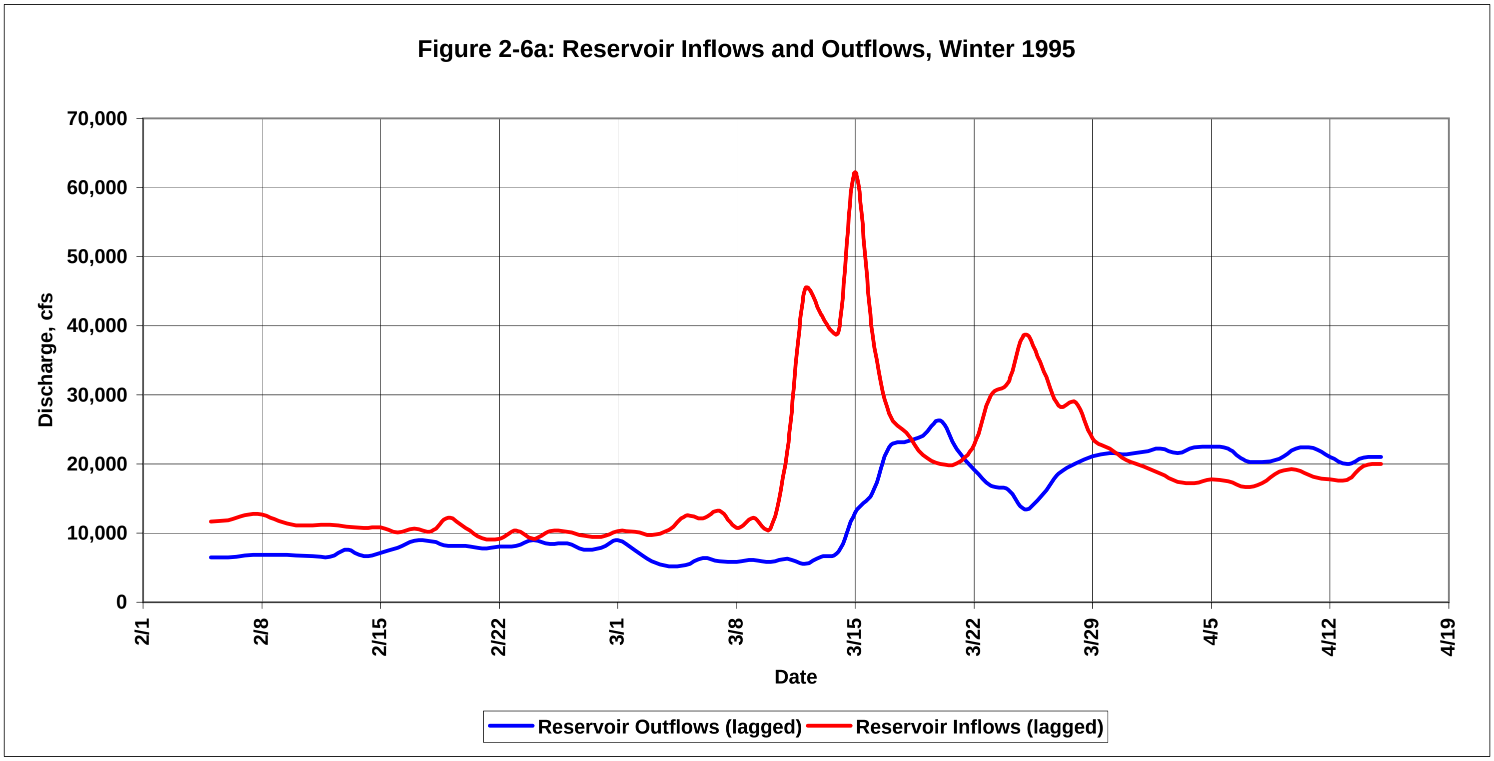
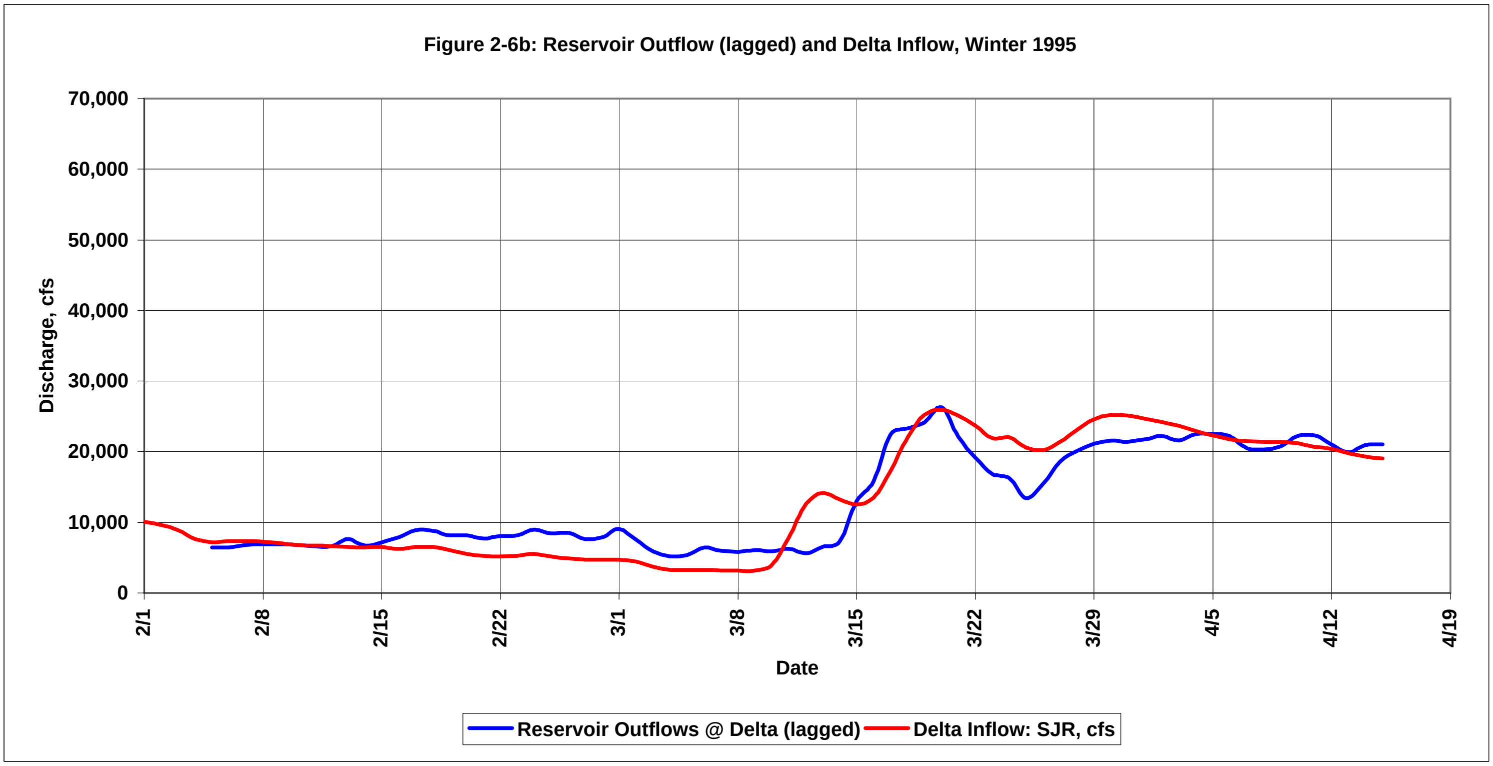


FIGURE 2-6: SAN JOAQUIN RIVER WATERSHED, WINTER 1995





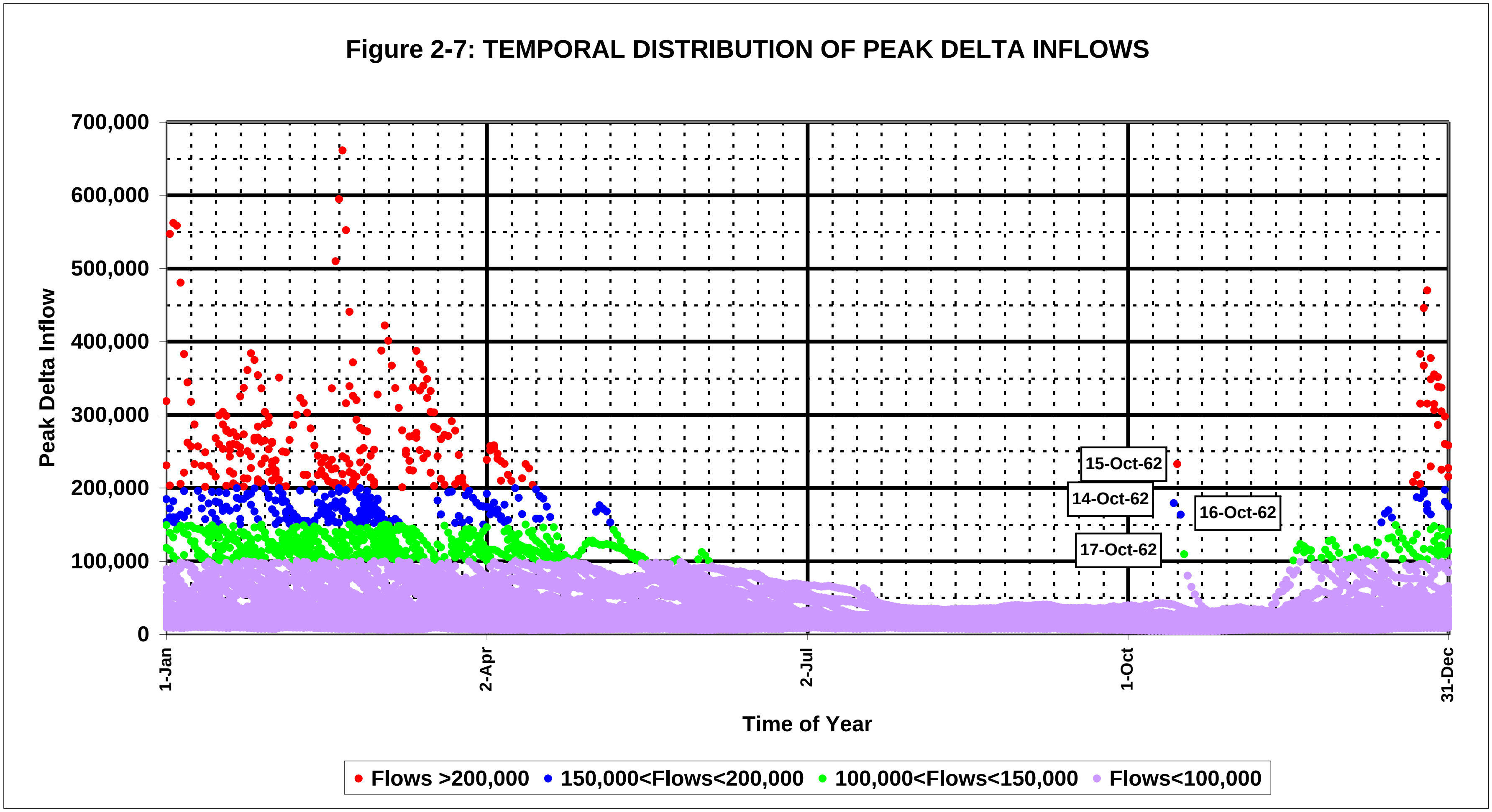


Figure 2-7: TEMPORAL DISTRIBUTION OF PEAK DELTA INFLOWS
Peak Delta Inflow
700,000
600,000
500,000
400,000
300,000
200,000
100,000
0
1-Jan
2-Apr
2-Jul
1-Oct
31-Dec
Time of Year
15-Oct-62
14-Oct-62
16-Oct-62
17-Oct-62
Flows >200,000
150,000<Flows<200,000
100,000<Flows<150,000
Flows<100,000

B - Fig 2-7

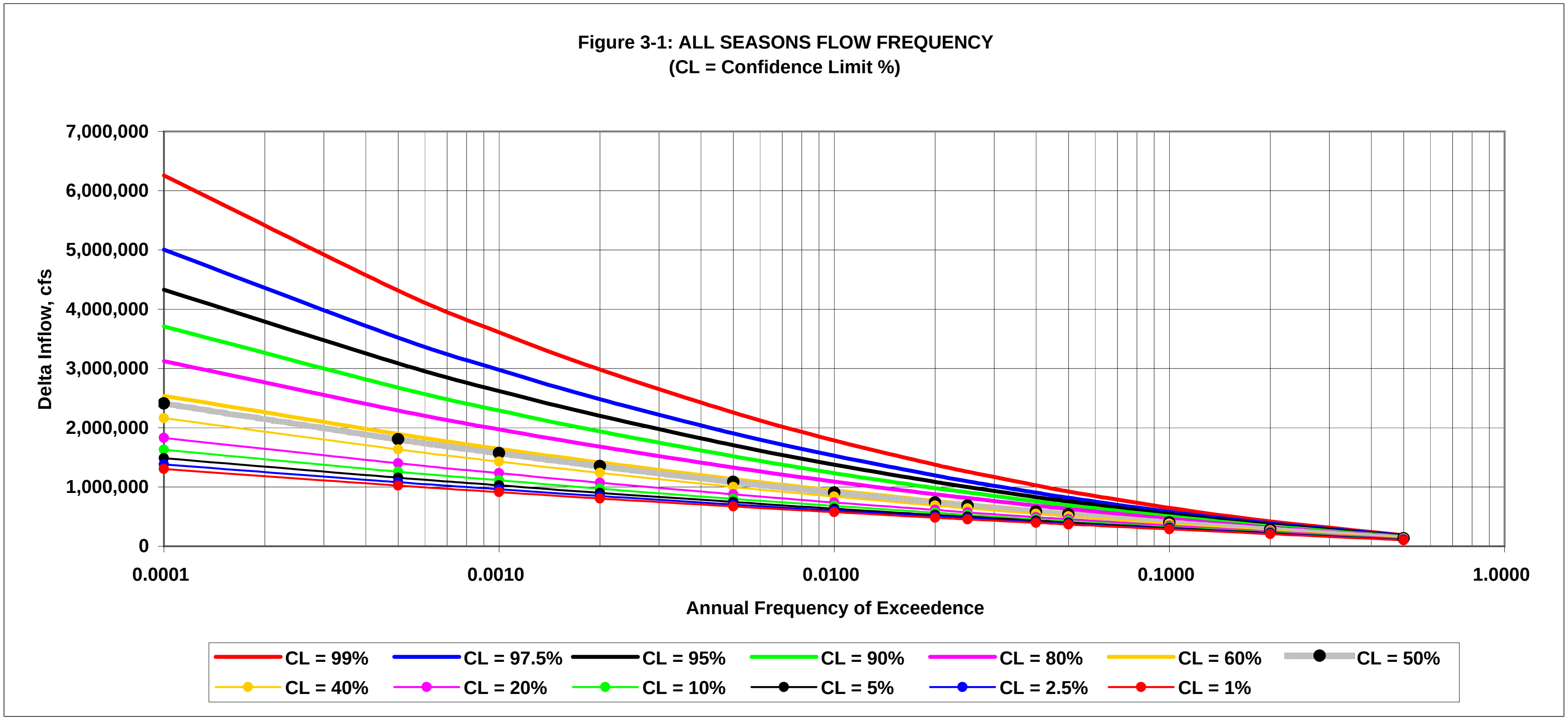


Figure 3-1: ALL SEASONS FLOW FREQUENCY
(CL = Confidence Limit %)
7,000,000
6,000,000
5,000,000
4,000,000
3,000,000
2,000,000
1,000,000
0
Delta Inflow, cfs
0.0001
0.0010
0.0100
0.1000
1.0000
Annual Frequency of Exceedence
CL = 99%
CL = 97.5%
CL = 95%
CL = 90%
CL = 80%
CL = 60%
CL = 50%
CL = 40%
CL = 20%
CL = 10%
CL = 5%
CL = 2.5%
CL = 1%

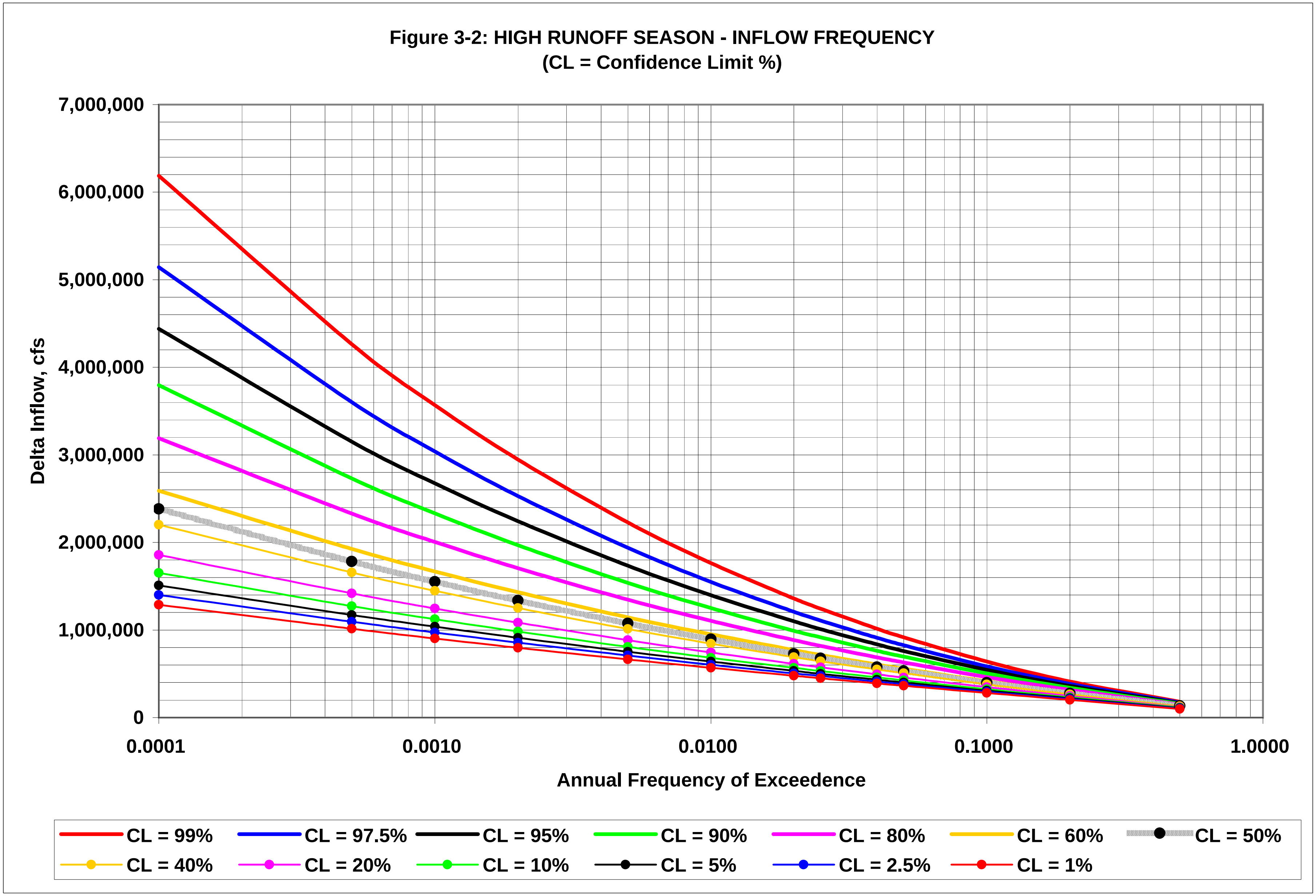


Figure 3-2: HIGH RUNOFF SEASON - INFLOW FREQUENCY
(CL = Confidence Limit %)
7,000,000
6,000,000
5,000,000
4,000,000
3,000,000
2,000,000
1,000,000
0
Delta Inflow, cfs
0.0001
0.0010
0.0100
0.1000
1.0000
Annual Frequency of Exceedence
CL = 99%
CL = 97.5%
CL = 95%
CL = 90%
CL = 80%
CL = 60%
CL = 50%
CL = 40%
CL = 20%
CL = 10%
CL = 5%
CL = 2.5%
CL = 1%

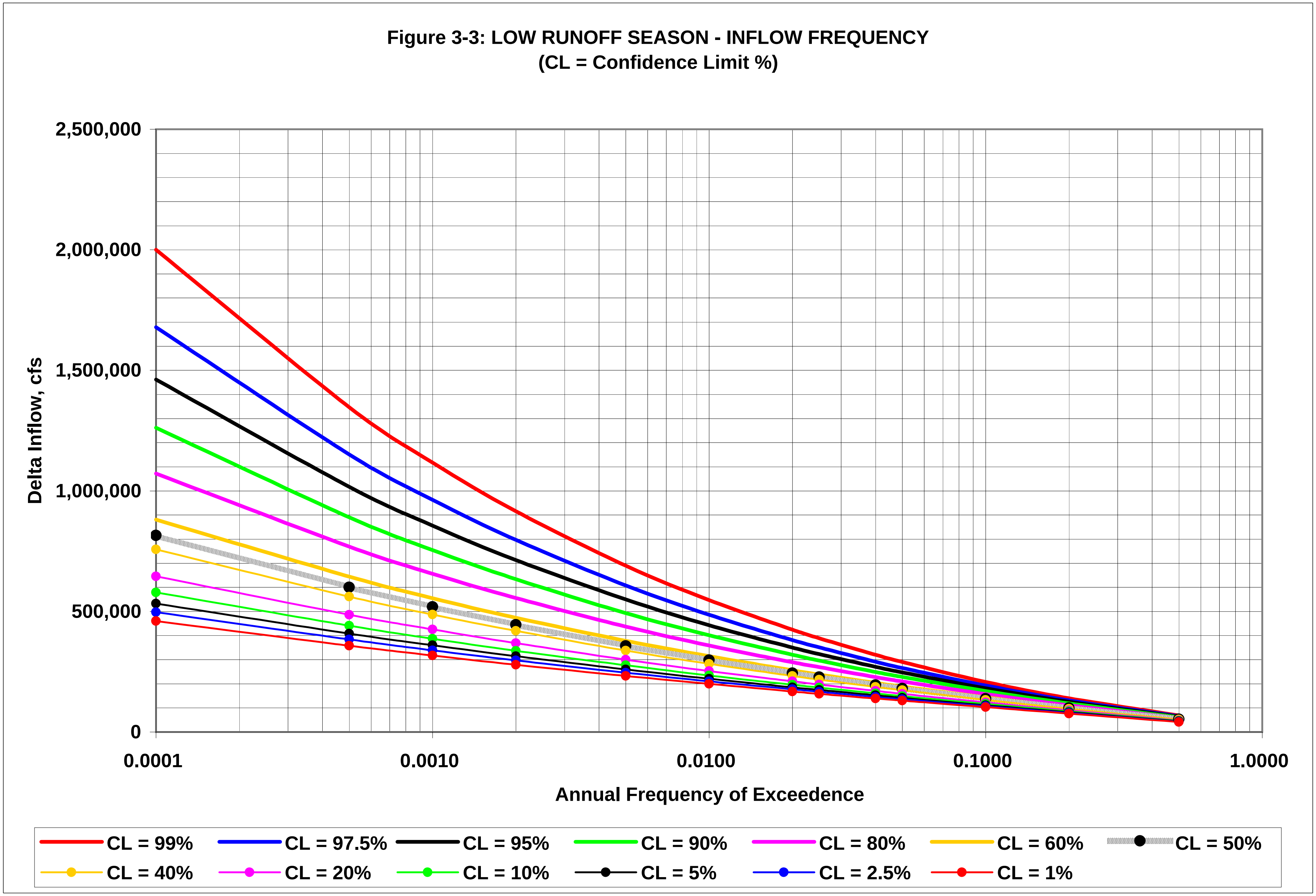


Figure 3-3: LOW RUNOFF SEASON - INFLOW FREQUENCY
(CL = Confidence Limit %)
Delta Inflow, cfs
2,500,000
2,000,000
1,500,000
1,000,000
500,000
0
0.0001
0.0010
0.0100
0.1000
1.0000
Annual Frequency of Exceedence
CL = 99%
CL = 97.5%
CL = 95%
CL = 90%
CL = 80%
CL = 60%
CL = 50%
CL = 40%
CL = 20%
CL = 10%
CL = 5%
CL = 2.5%
CL = 1%

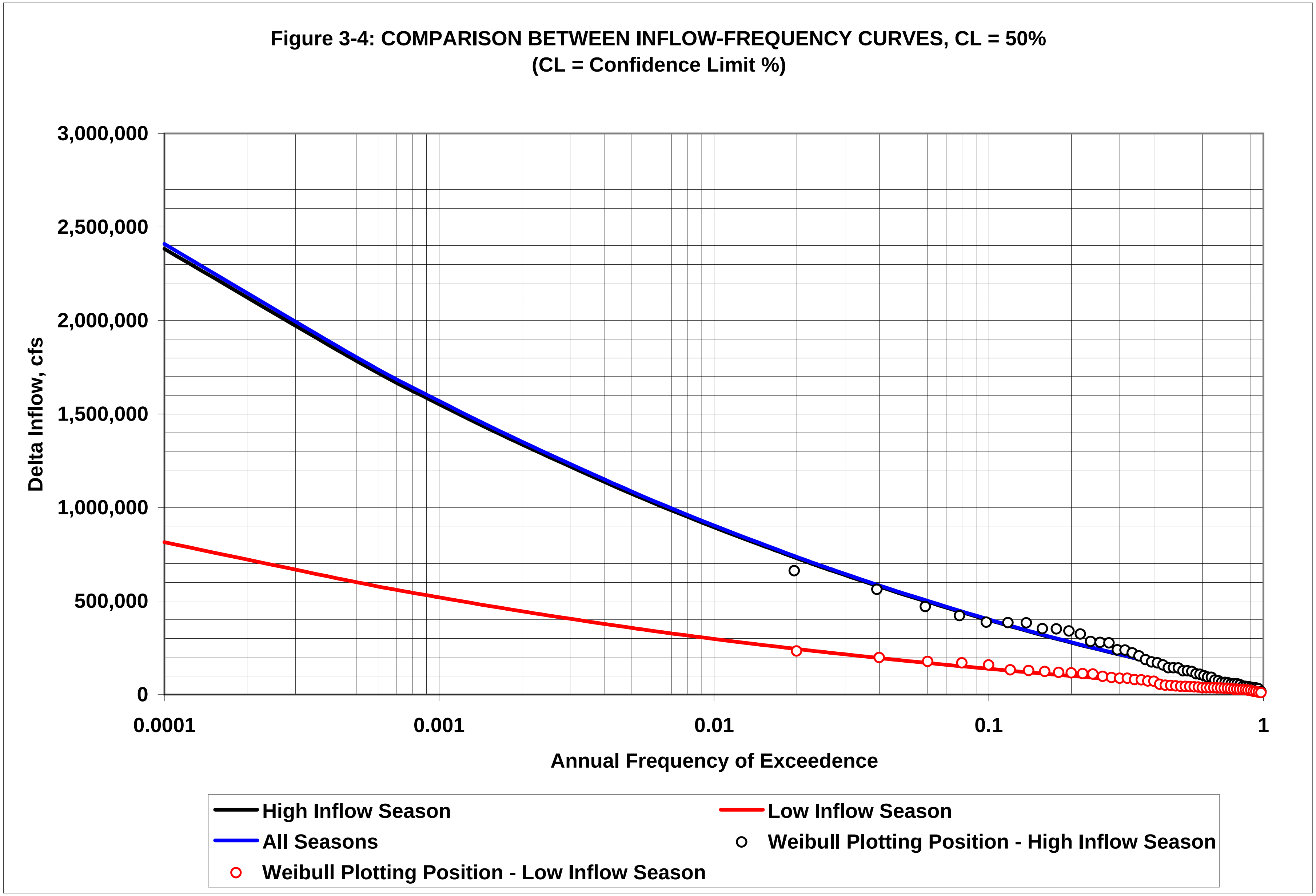


Figure 3-4: COMPARISON BETWEEN INFLOW-FREQUENCY CURVES, CL = 50%
(CL = Confidence Limit %)
3,000,000
2,500,000
2,000,000
1,500,000
1,000,000
500,000
0
Delta Inflow, cfs
0.0001
0.001
0.01
0.1
1
Annual Frequency of Exceedence
High Inflow Season
Low Inflow Season
All Seasons
Weibull Plotting Position - High Inflow Season
Weibull Plotting Position - Low Inflow Season

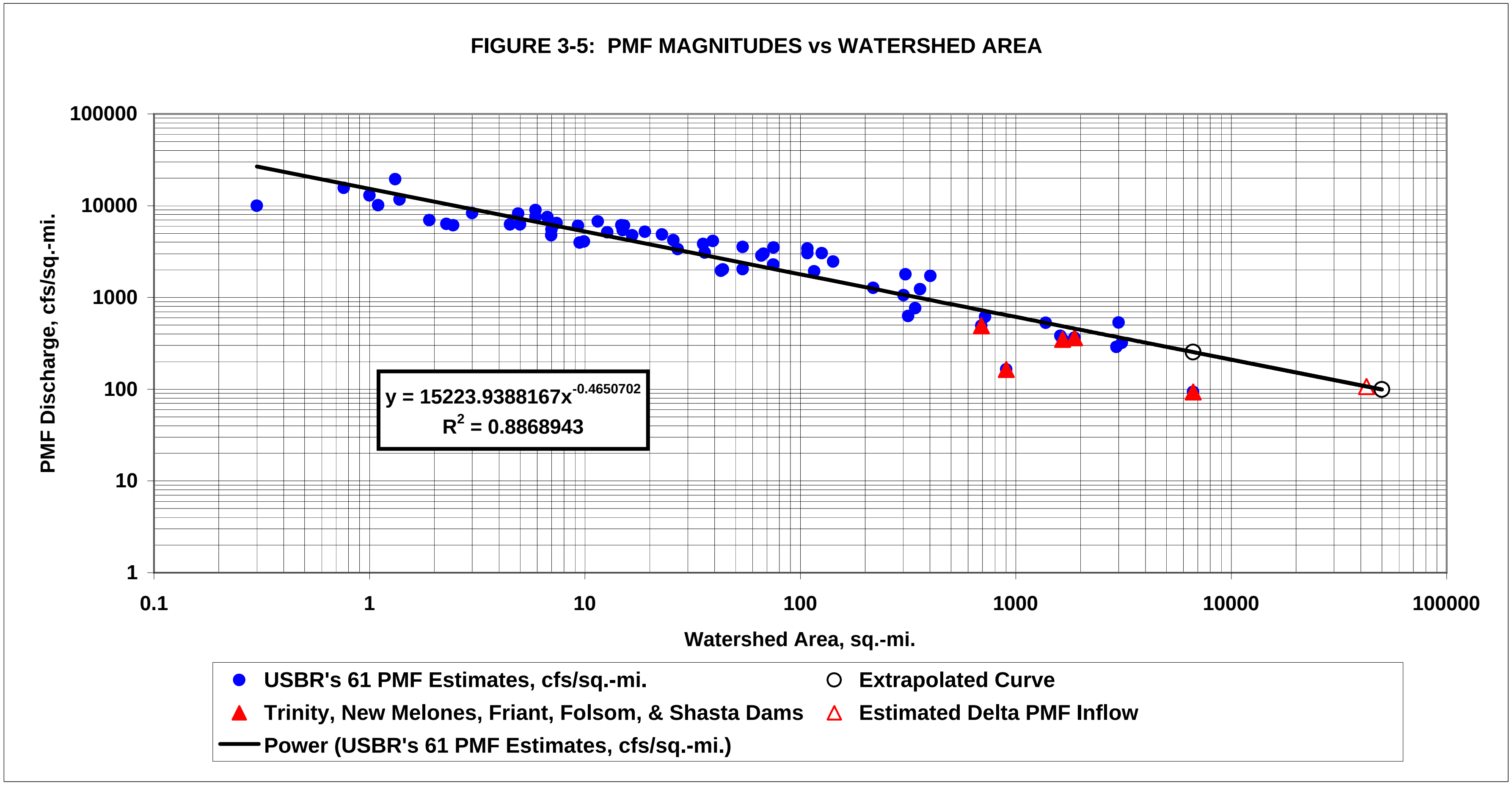


FIGURE 3-5: PMF MAGNITUDES vs WATERSHED AREA
PMF Discharge, cfs/sq.-mi.
100000
10000
1000
100
10
1
0.1
1
10
100
1000
10000
100000
Watershed Area, sq.-mi.
y = 15223.9388167x^-0.4650702
R^2 = 0.8868943
USBR's 61 PMF Estimates, cfs/sq.-mi.
Trinity, New Melones, Friant, Folsom, & Shasta Dams
Power (USBR's 61 PMF Estimates, cfs/sq.-mi.)
Extrapolated Curve
Estimated Delta PMF Inflow

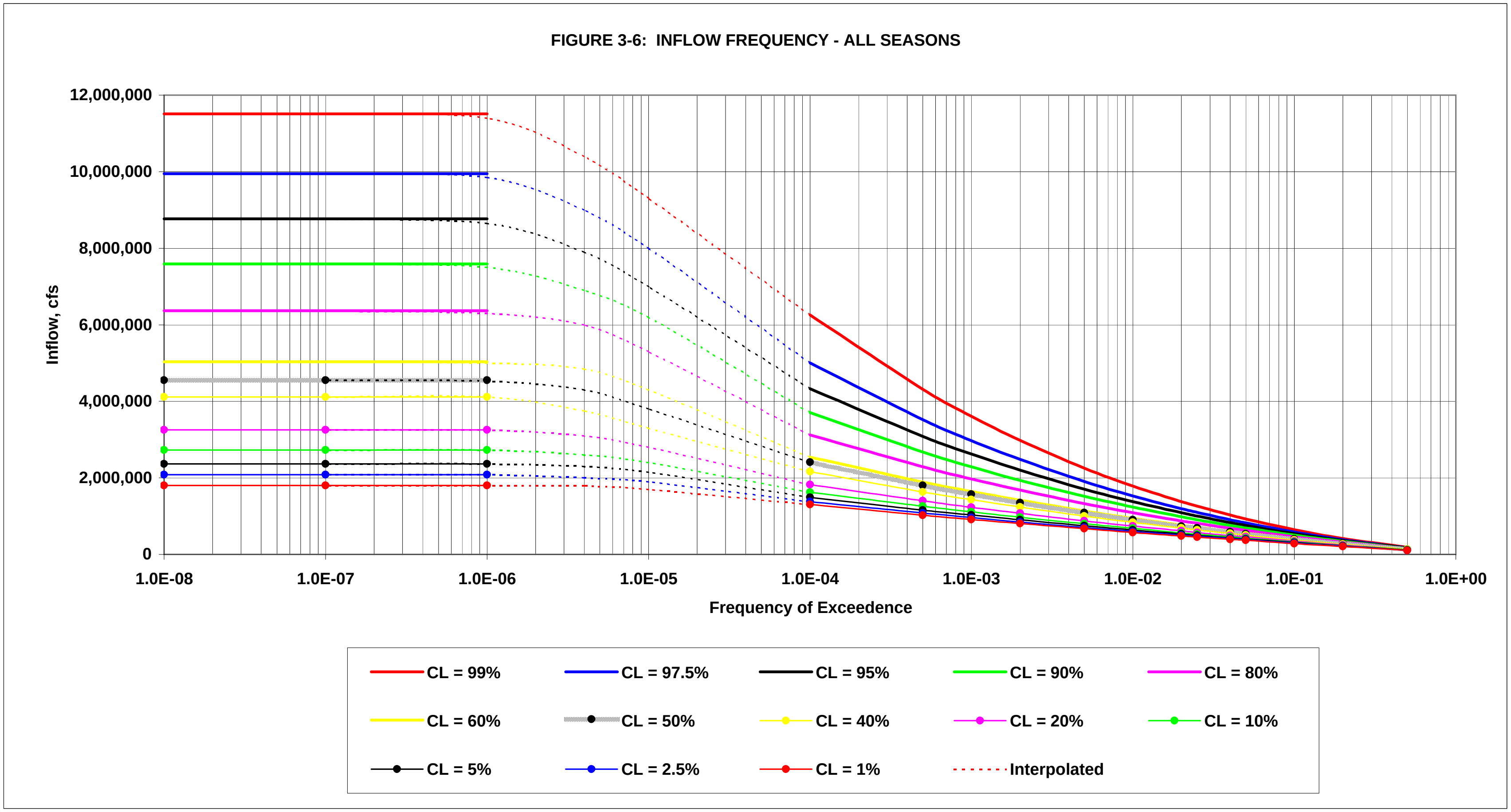
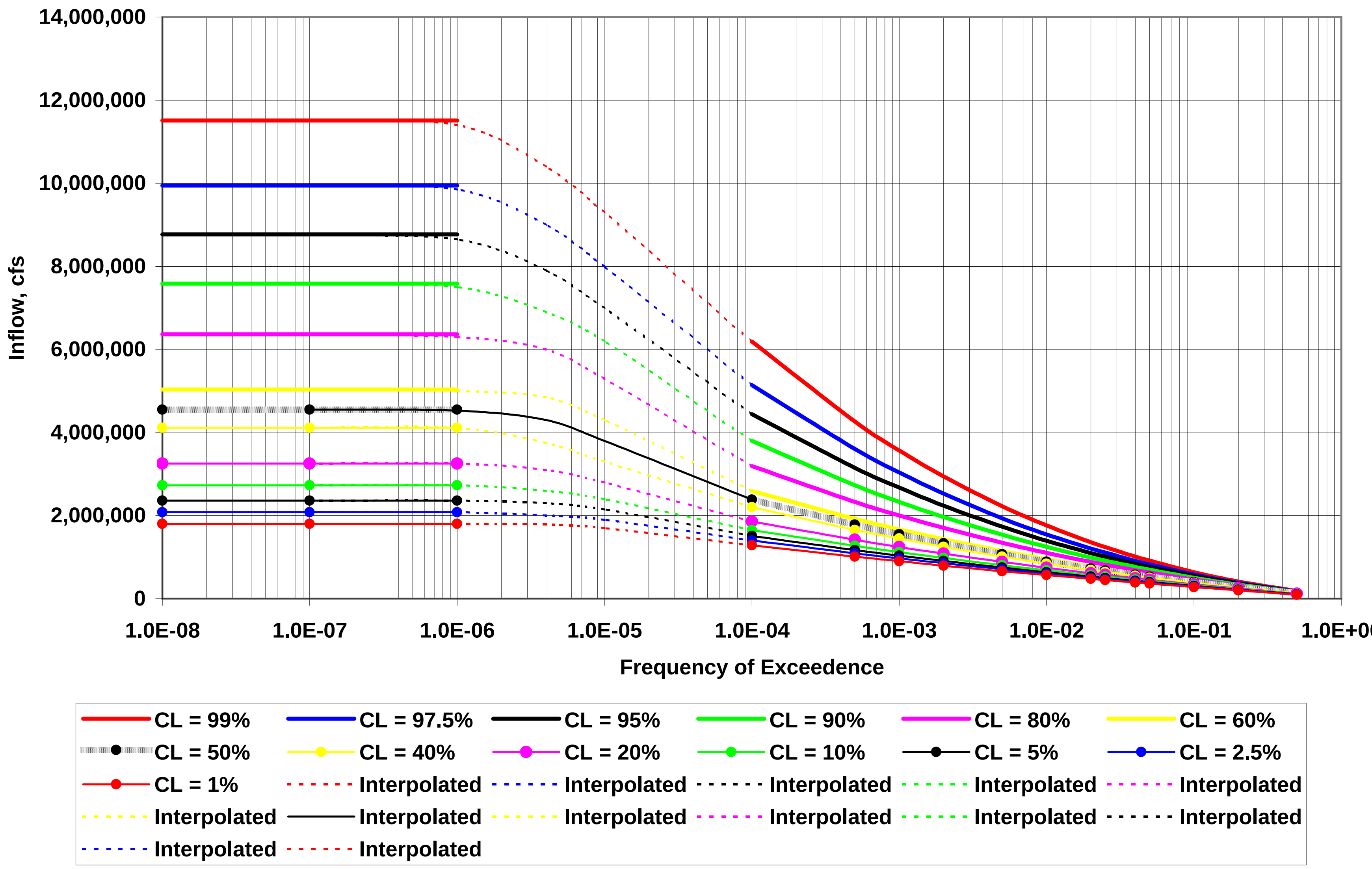
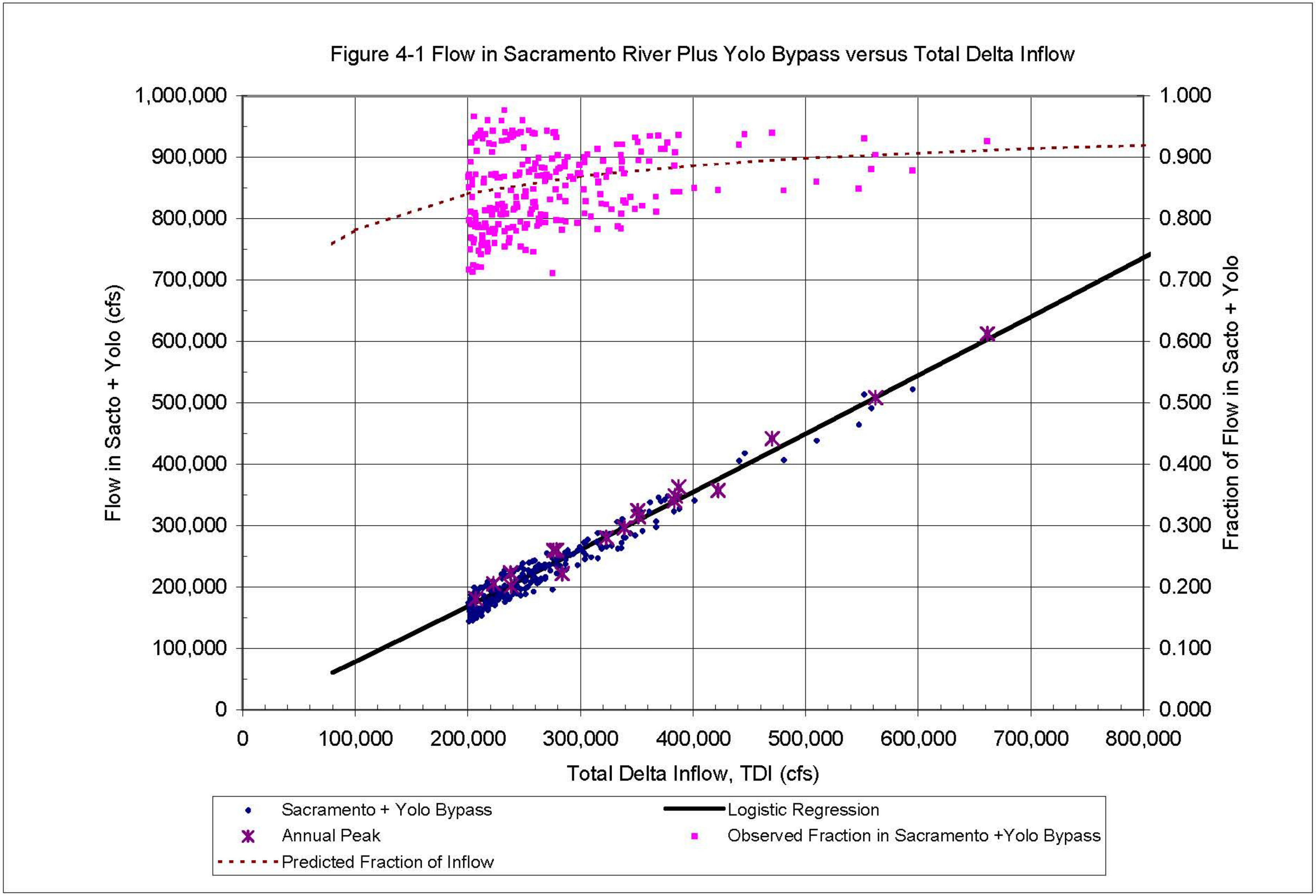


FIGURE 3-6: INFLOW FREQUENCY - ALL SEASONS
12,000,000
10,000,000
8,000,000
6,000,000
4,000,000
2,000,000
0
Inflow, cfs
1.0E-08
1.0E-07
1.0E-06
1.0E-05
1.0E-04
1.0E-03
1.0E-02
1.0E-01
1.0E+00
Frequency of Exceedence
CL = 99%
CL = 97.5%
CL = 95%
CL = 90%
CL = 80%
CL = 60%
CL = 50%
CL = 40%
CL = 20%
CL = 10%
CL = 5%
CL = 2.5%
CL = 1%
Interpolated

FIGURE 3-7: FLOW FREQUENCY - HIGH INFLOW SEASON, 2000





Q.GT.80k.xls-SActo+Yolo Chart 1

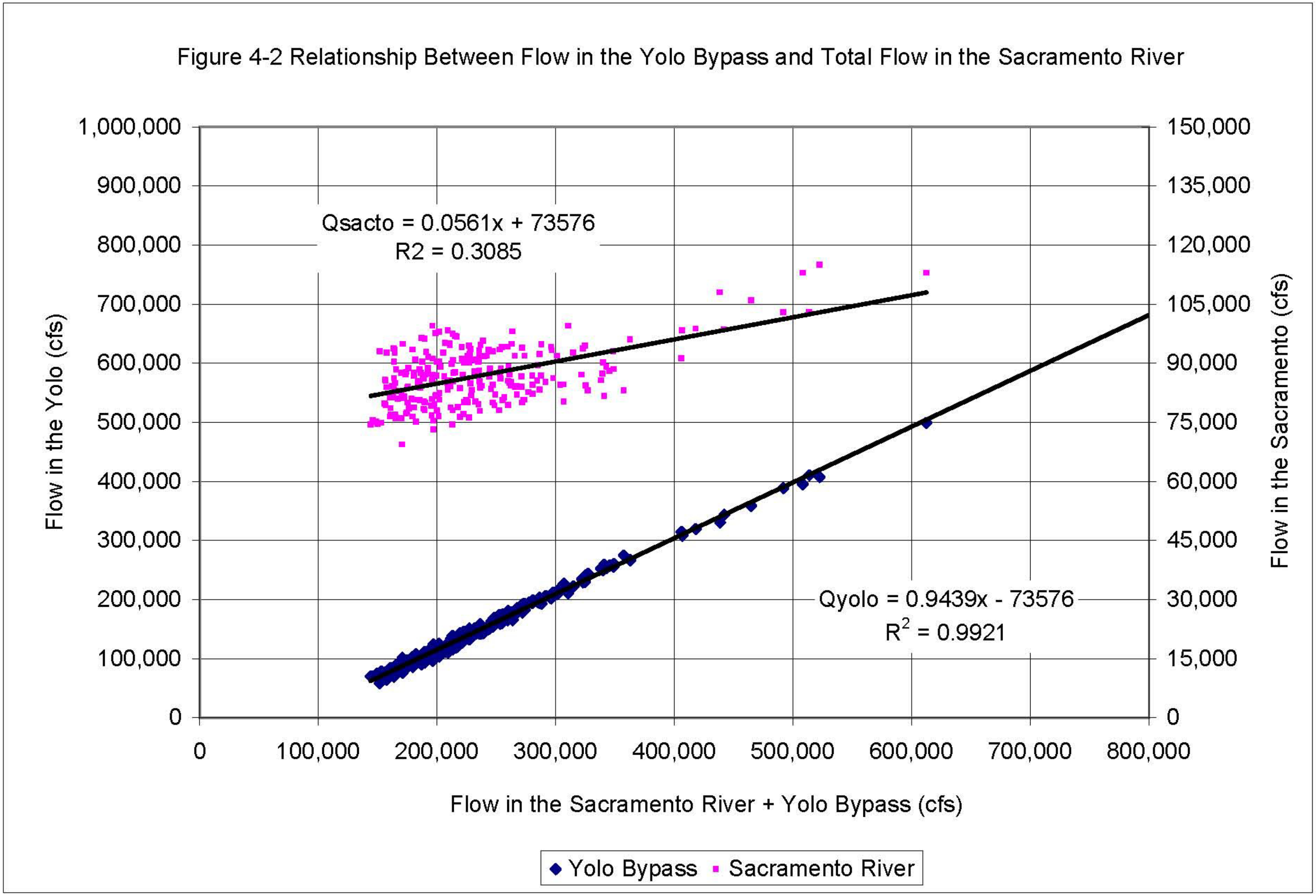
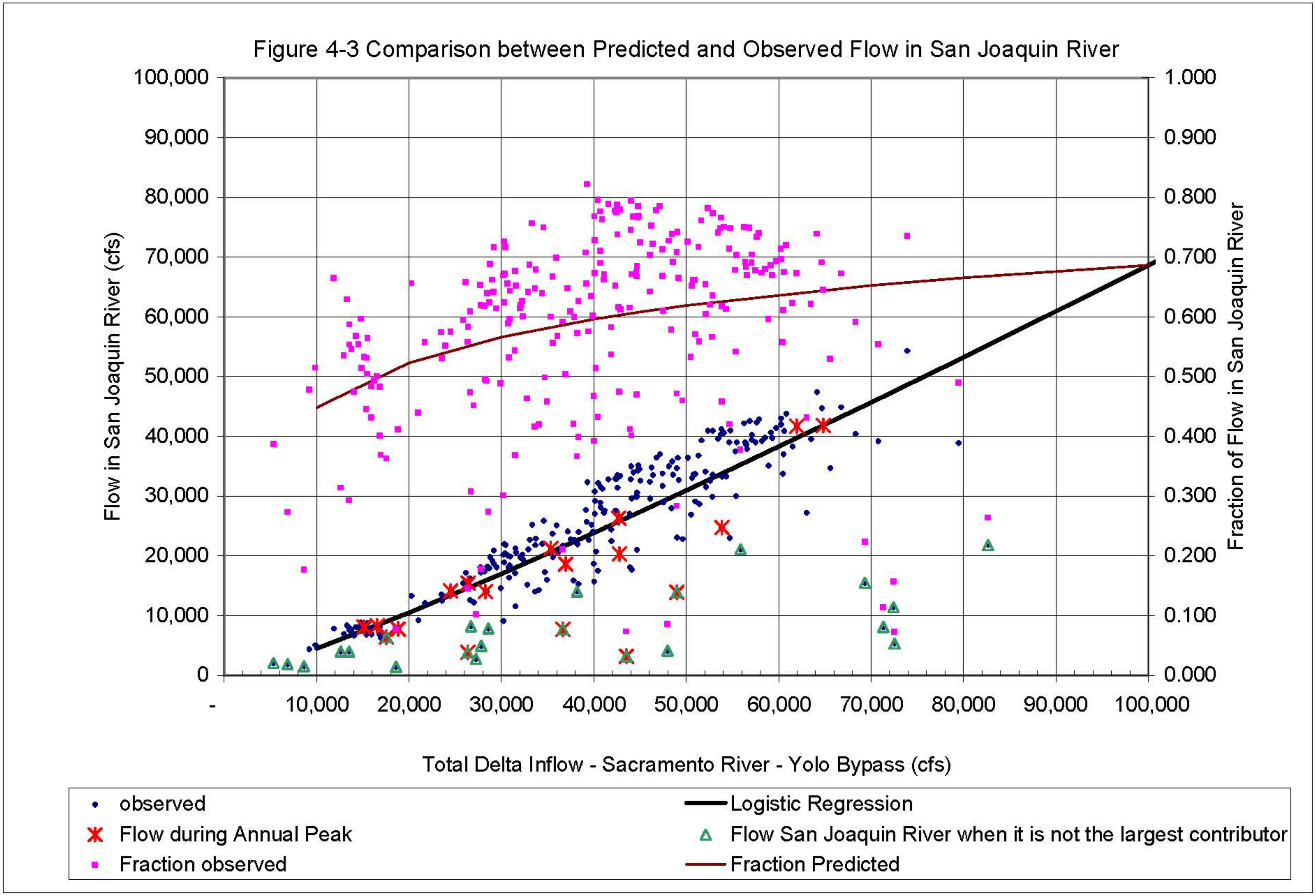
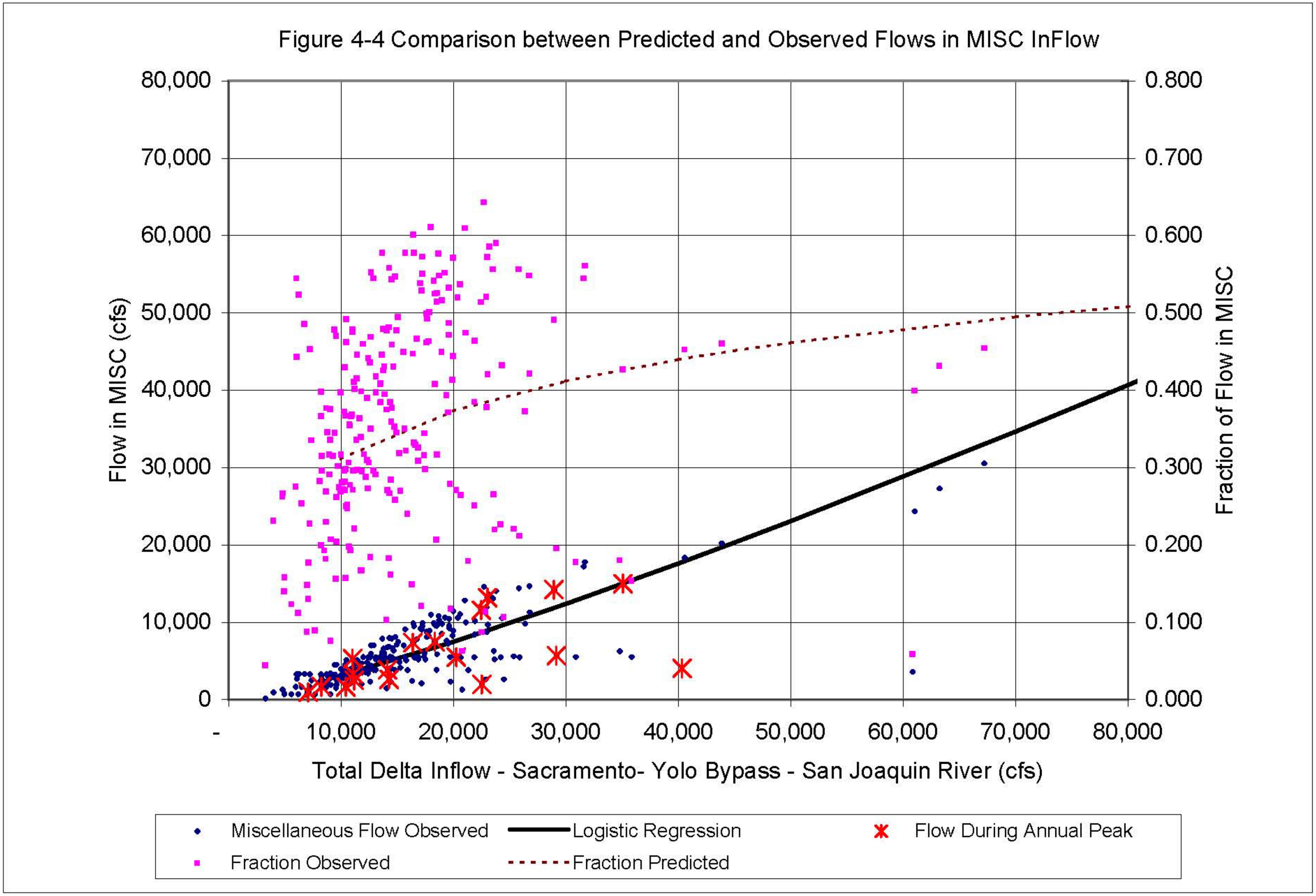


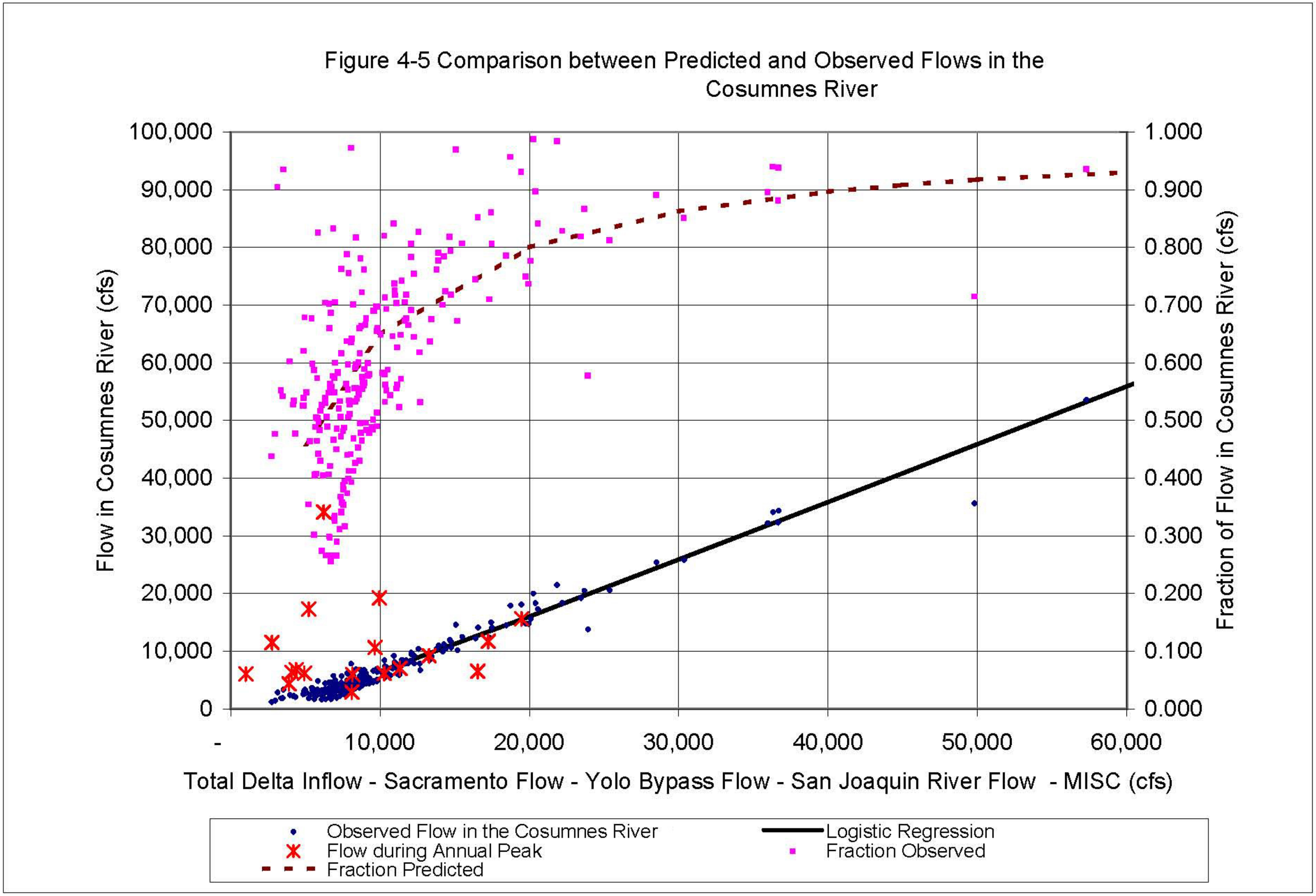
Figure 4-2 Relationship Between Flow in the Yolo Bypass and Total Flow in the Sacramento River
Qsacto = 0.0561x + 73576
R2 = 0.3085
Qyolo = 0.9439x - 73576
R^2 = 0.9921
Flow in the Yolo (cfs)
Flow in the Sacramento (cfs)
Flow in the Sacramento River + Yolo Bypass (cfs)
1,000,000
900,000
800,000
700,000
600,000
500,000
400,000
300,000
200,000
100,000
0
150,000
135,000
120,000
105,000
90,000
75,000
60,000
45,000
30,000
15,000
0
100,000
200,000
300,000
400,000
500,000
600,000
700,000
800,000
Yolo Bypass
Sacramento River



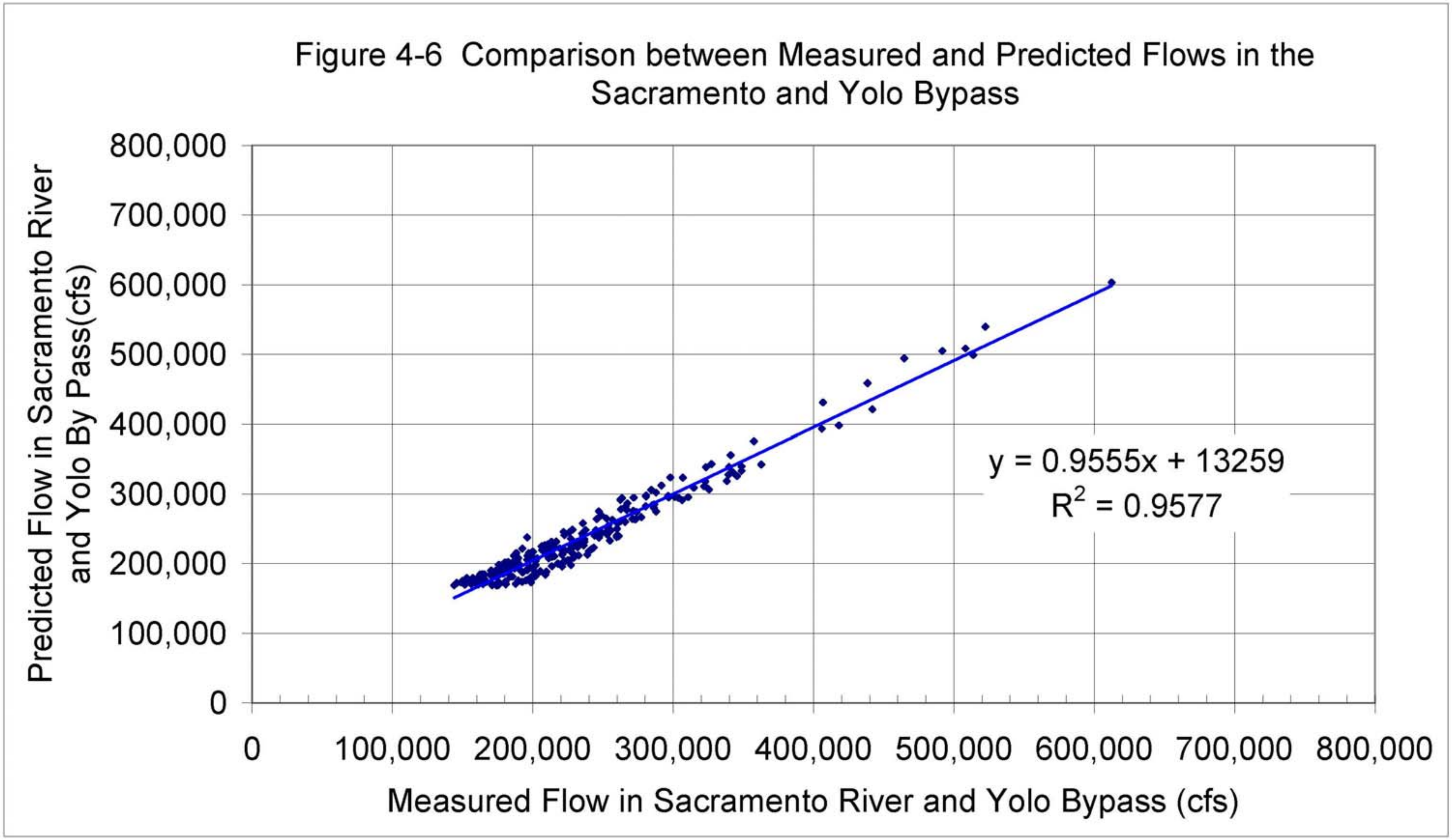
Q.gt.80k.xls-SJR Chart 1



Q.GT.80k.xls-Misc (0) Chart 1

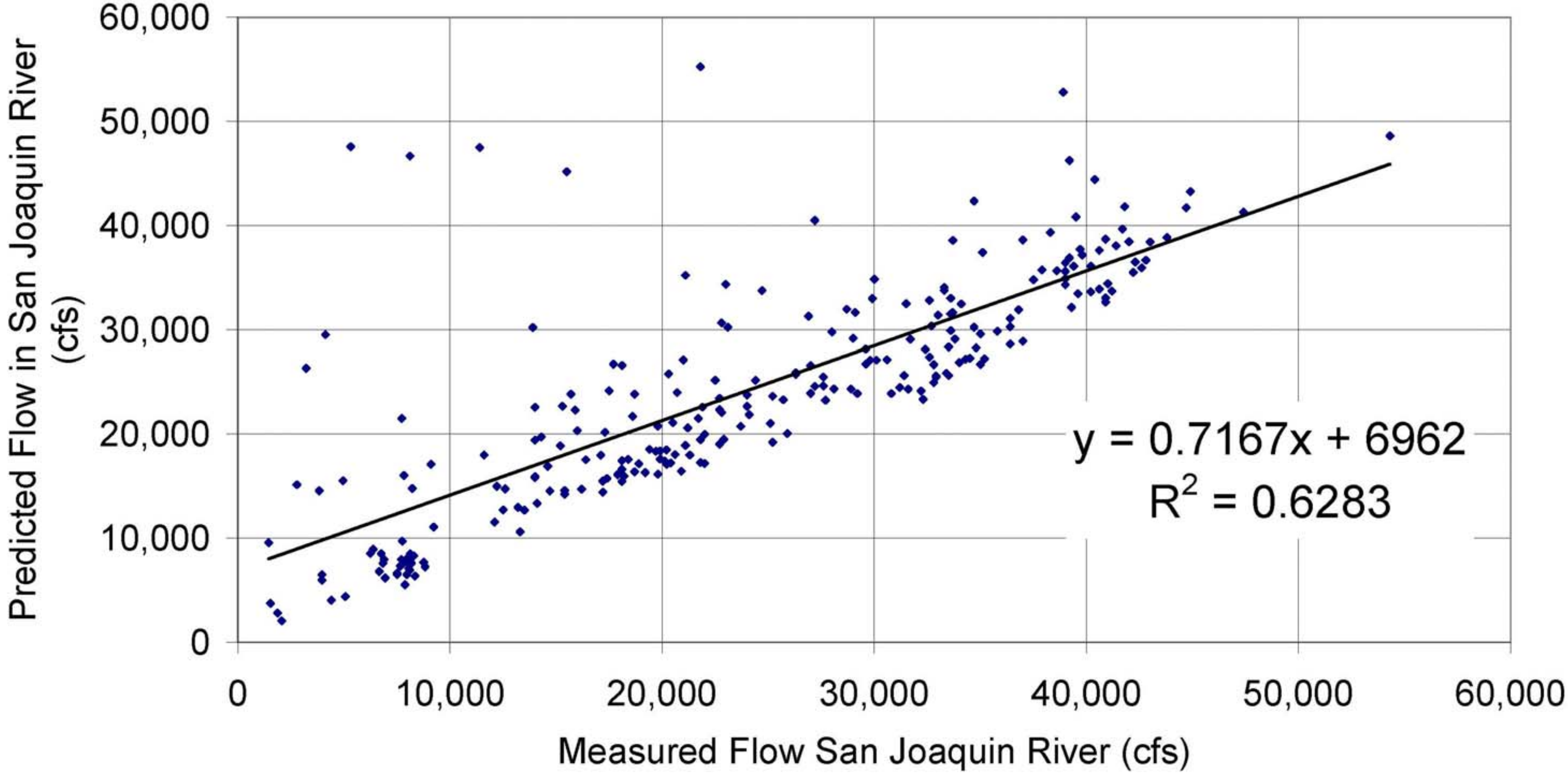


Q.gt.80k.xls-CSMR (3) Chart 1

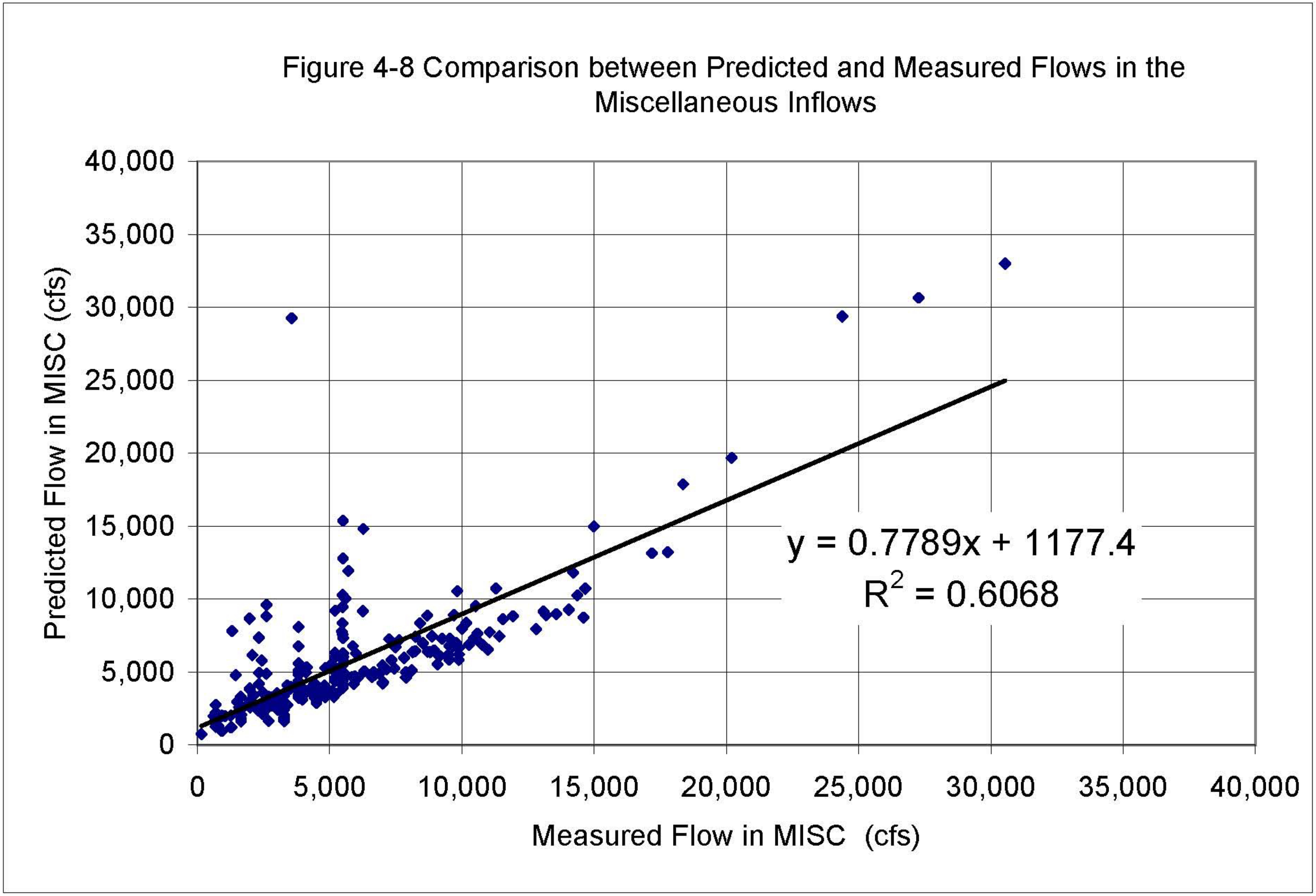


Q.gt.80k.xls-SActo+Yolo Chart 2

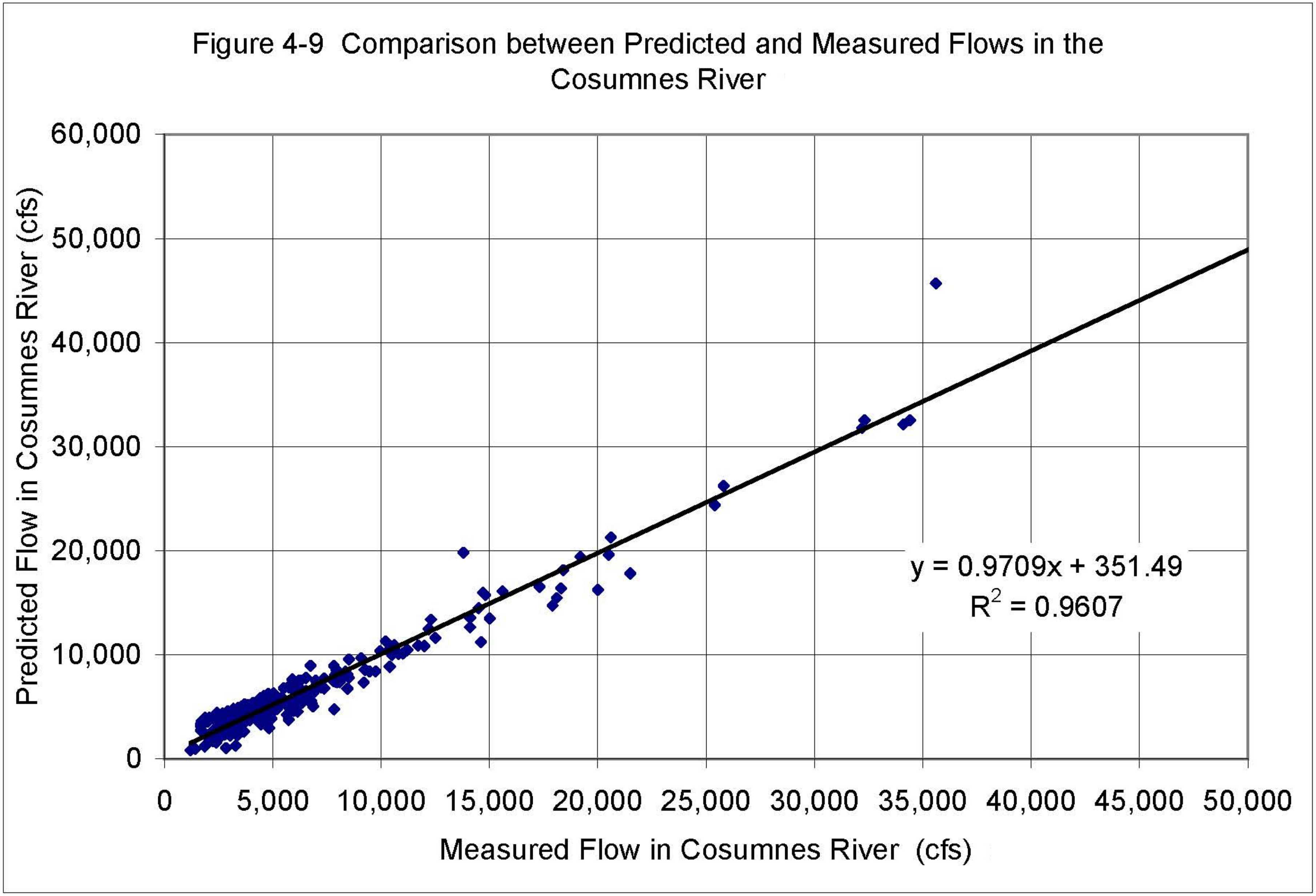
Figure 4-7 Comparison between Measured and Predicted Flows in the San Joaquin River



Q.gt 80k.xls-SJR Chart 2



Q.gt.80k.xls-Misc (0) Chart 2



Q.gt.80k.xls-CSMR (3) Chart 2

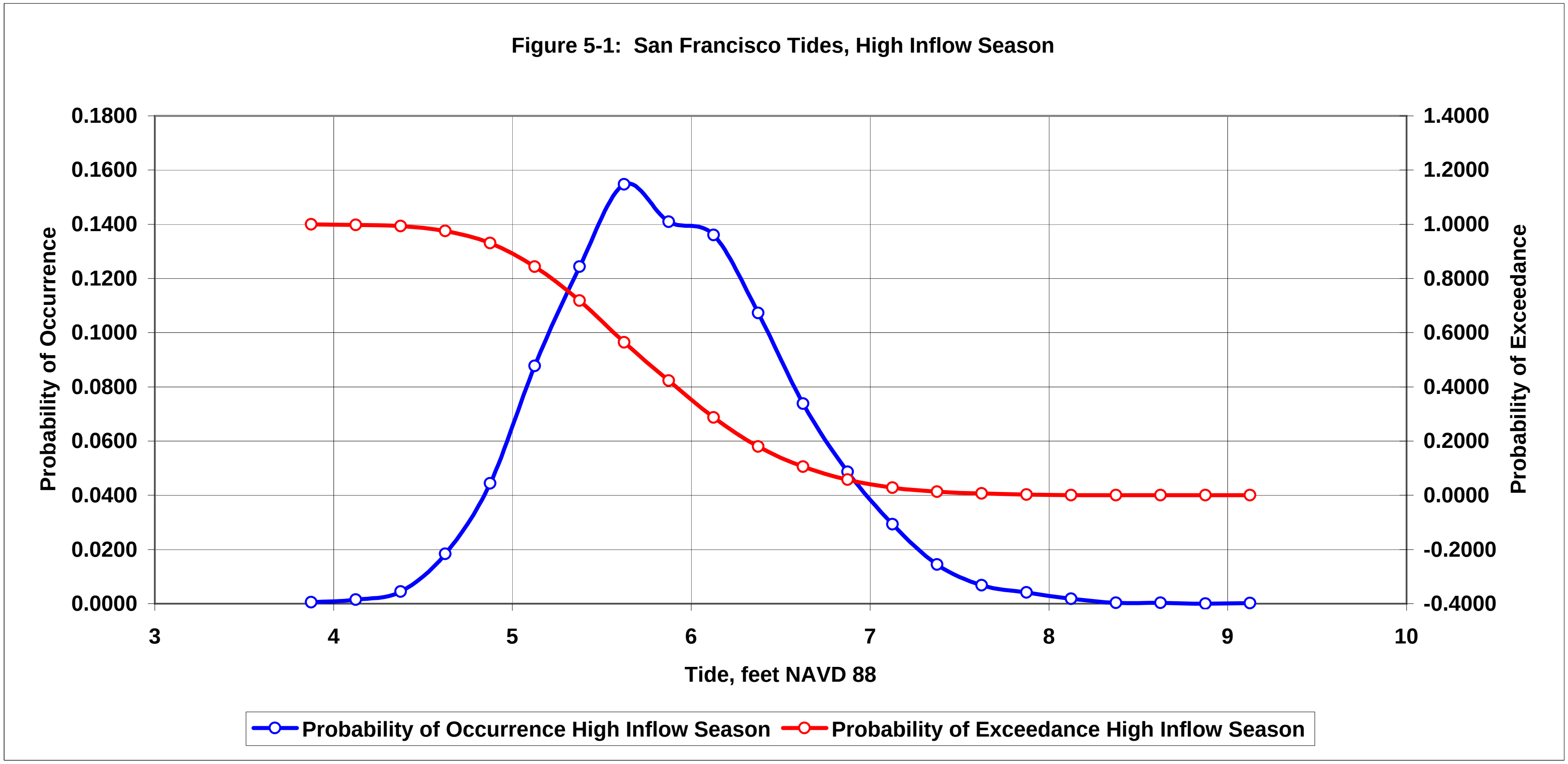
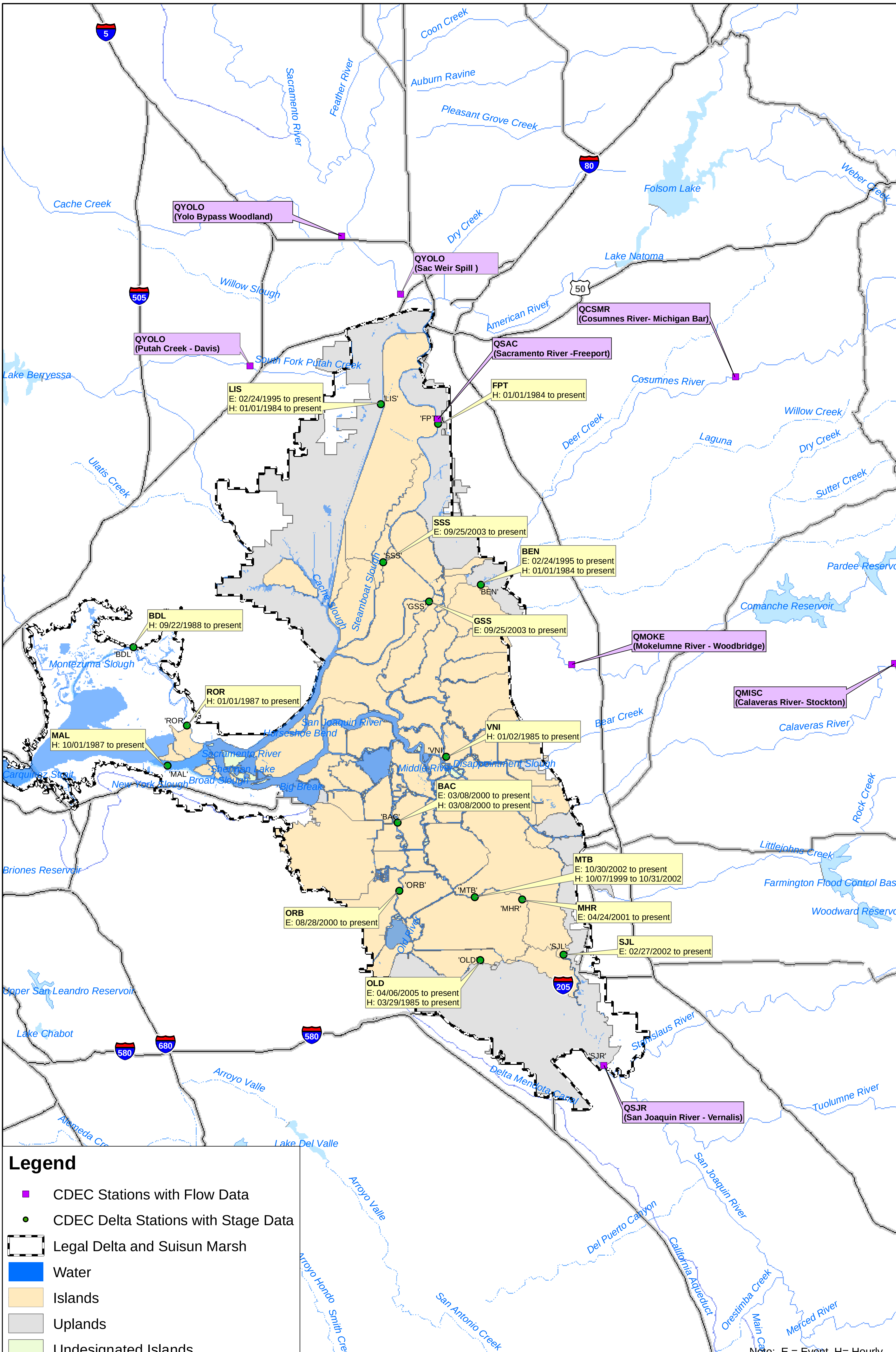


Figure 5-1: San Francisco Tides, High Inflow Season
Probability of Occurrence
Probability of Exceedance
0.1800
0.1600
0.1400
0.1200
0.1000
0.0800
0.0600
0.0400
0.0200
0.0000
1.4000
1.2000
1.0000
0.8000
0.6000
0.4000
0.2000
0.0000
-0.2000
-0.4000
3
4
5
6
7
8
9
10
Tide, feet NAVD 88
Probability of Occurrence High Inflow Season
Probability of Exceedance High Inflow Season



URS Corporation P:\GIS\GIS_Project_Files\OriginalData\Regional_Data\CDEC_stations\Stations_used_for_regression_analyses.mxd Date: 12/14/2006 2:20:39 PM Name: smlewis0

URS | DRMS 26815431 | Stations Used for Regression Analyses | Figure 5-2

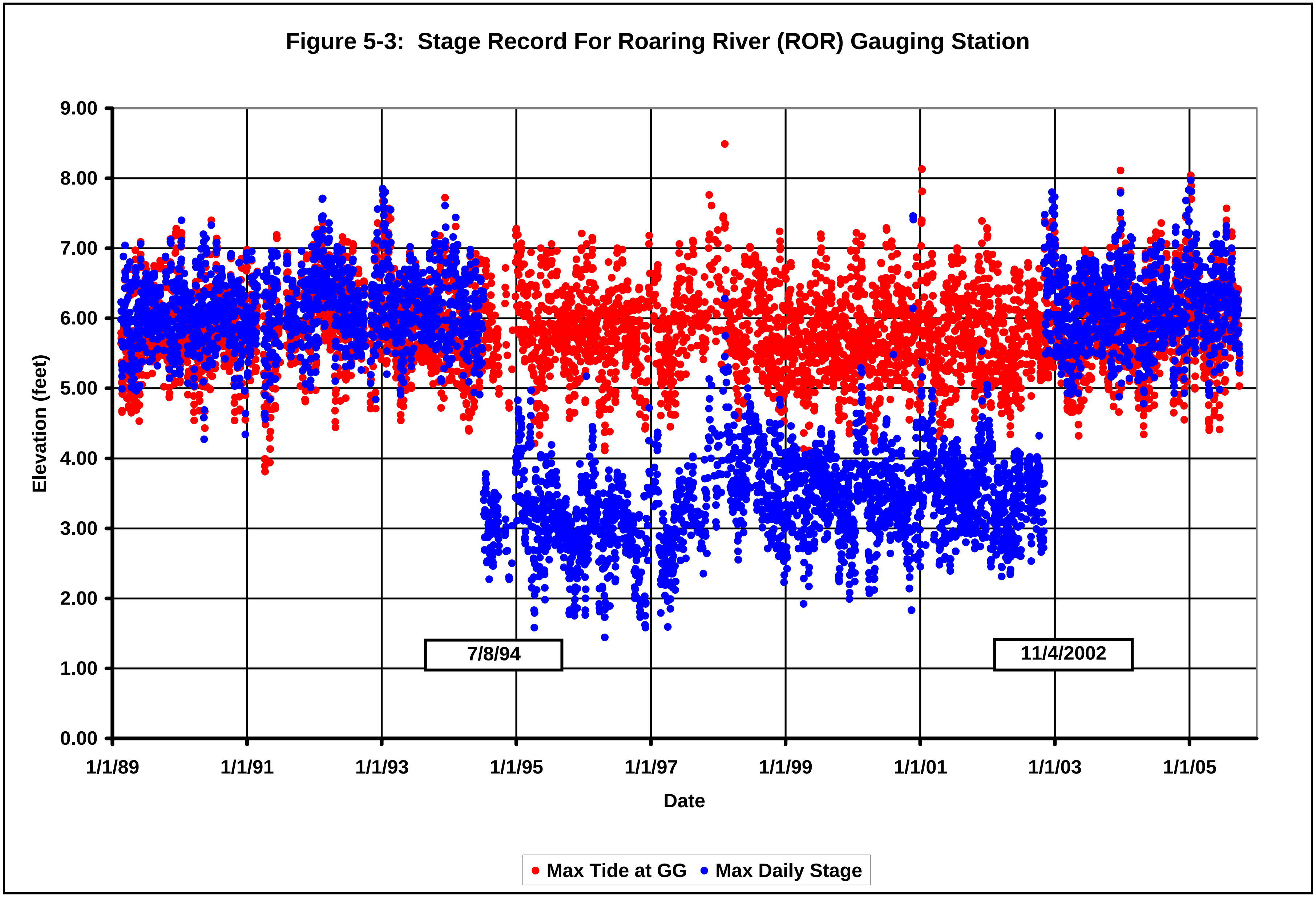
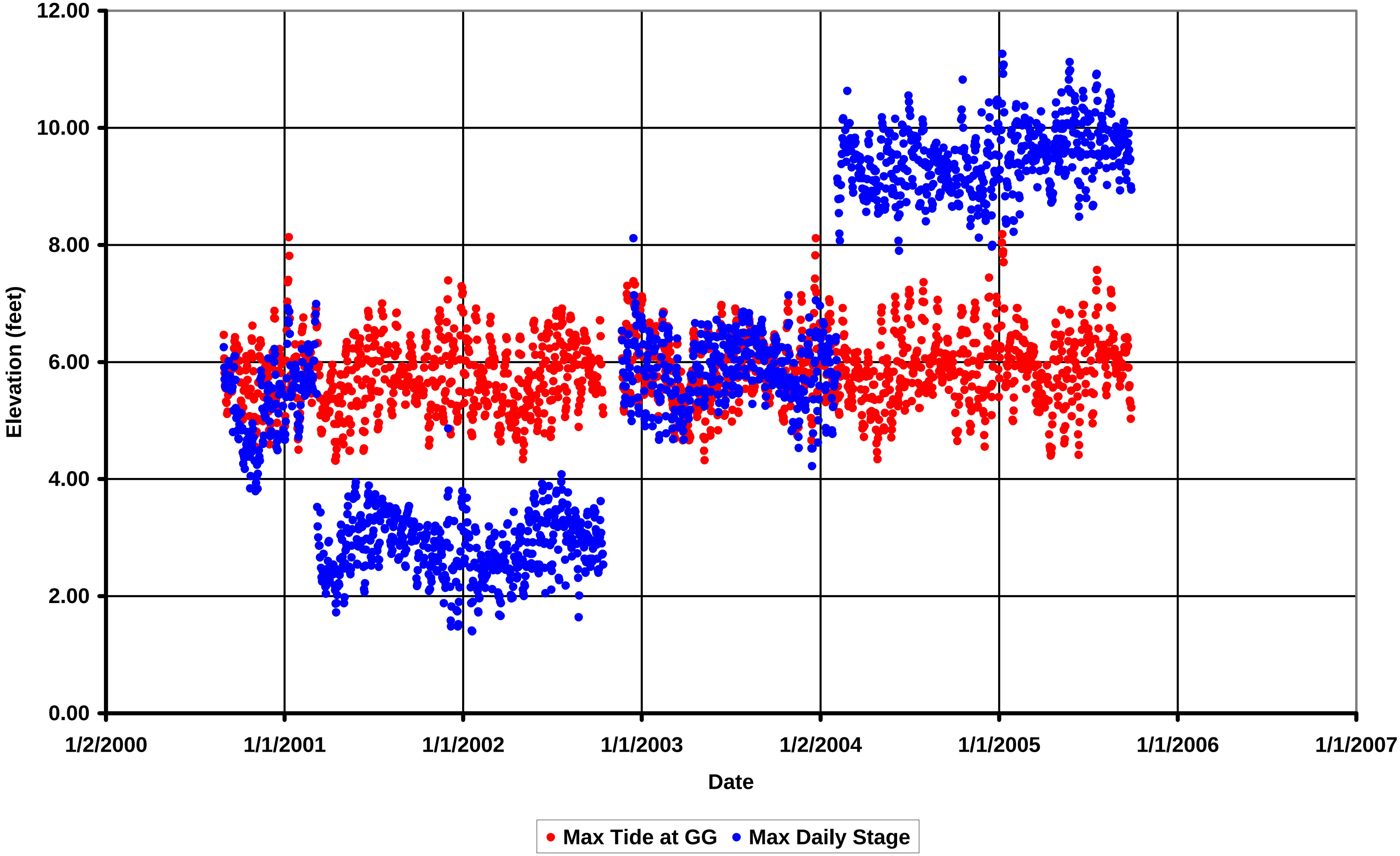


Figure 5-3: Stage Record For Roaring River (ROR) Gauging Station
Elevation (feet)
9.00
8.00
7.00
6.00
5.00
4.00
3.00
2.00
1.00
0.00
7/8/94
11/4/2002
1/1/89
1/1/91
1/1/93
1/1/95
1/1/97
1/1/99
1/1/01
1/1/03
1/1/05
Date
Max Tide at GG
Max Daily Stage

Figure 5-4: Stage Record For Old River At Byron (ORB) Gauging Station



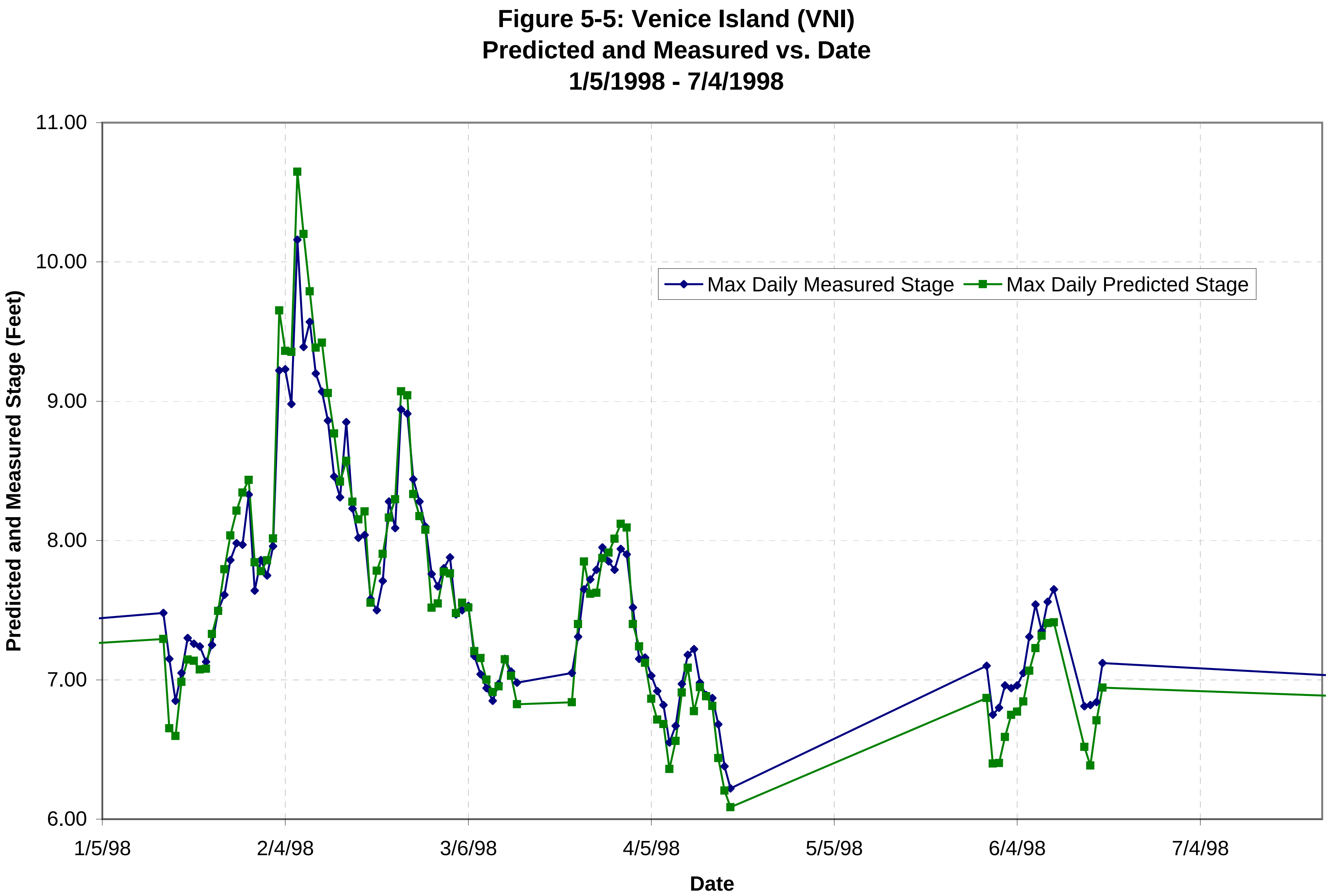


Figure 5-5: Venice Island (VNI)
Predicted and Measured vs. Date
1/5/1998 - 7/4/1998
Predicted and Measured Stage (Feet)
11.00
10.00
9.00
8.00
7.00
6.00
Max Daily Measured Stage
Max Daily Predicted Stage
1/5/98
2/4/98
3/6/98
4/5/98
5/5/98
6/4/98
7/4/98
Date

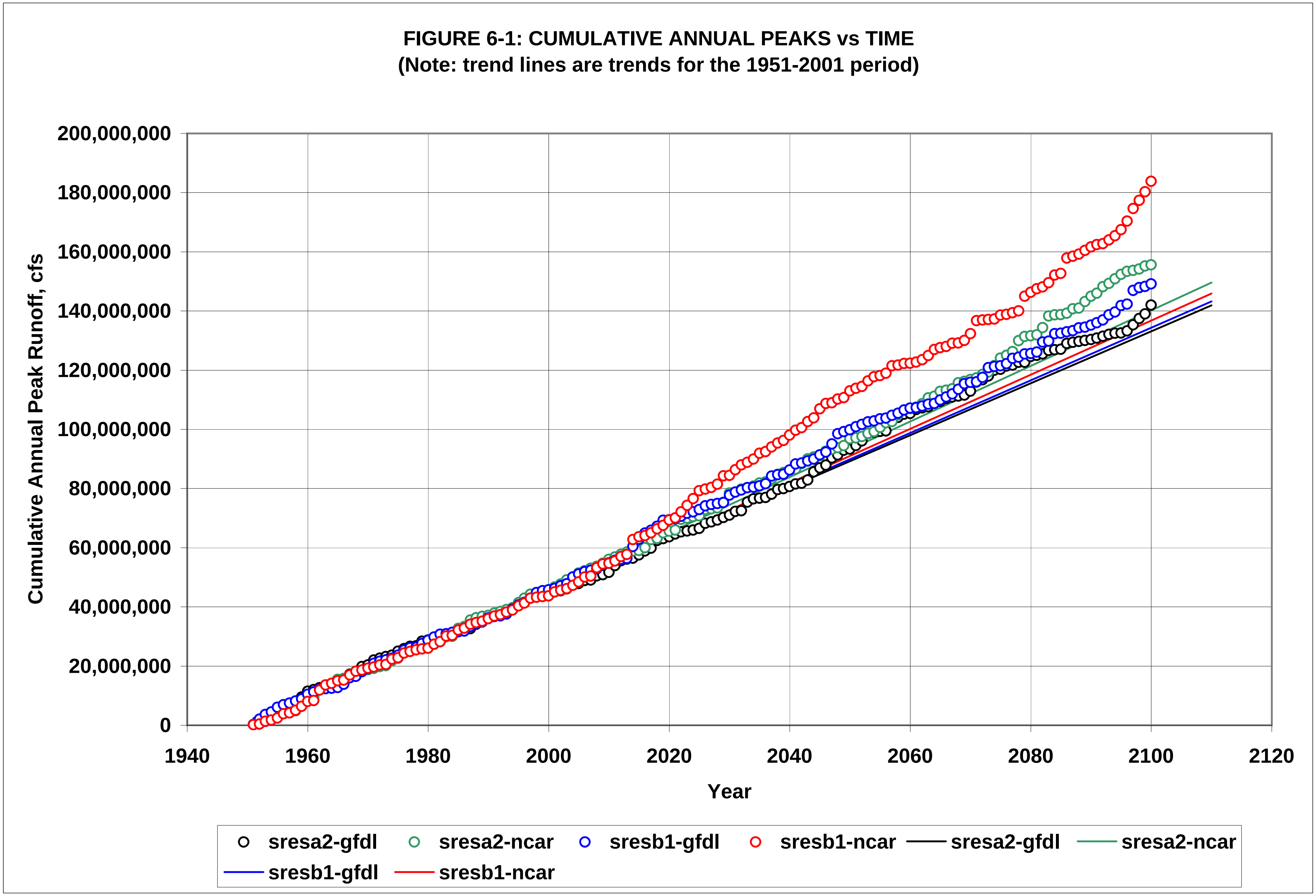


FIGURE 6-1: CUMULATIVE ANNUAL PEAKS vs TIME
(Note: trend lines are trends for the 1951-2001 period)
Cumulative Annual Peak Runoff, cfs
200,000,000
180,000,000
160,000,000
140,000,000
120,000,000
100,000,000
80,000,000
60,000,000
40,000,000
20,000,000
0
1940
1960
1980
2000
2020
2040
2060
2080
2100
2120
Year
sresa2-gfdl
sresa2-ncar
sresb1-gfdl
sresb1-ncar
sresa2-gfdl
sresa2-ncar
sresb1-gfdl
sresb1-ncar

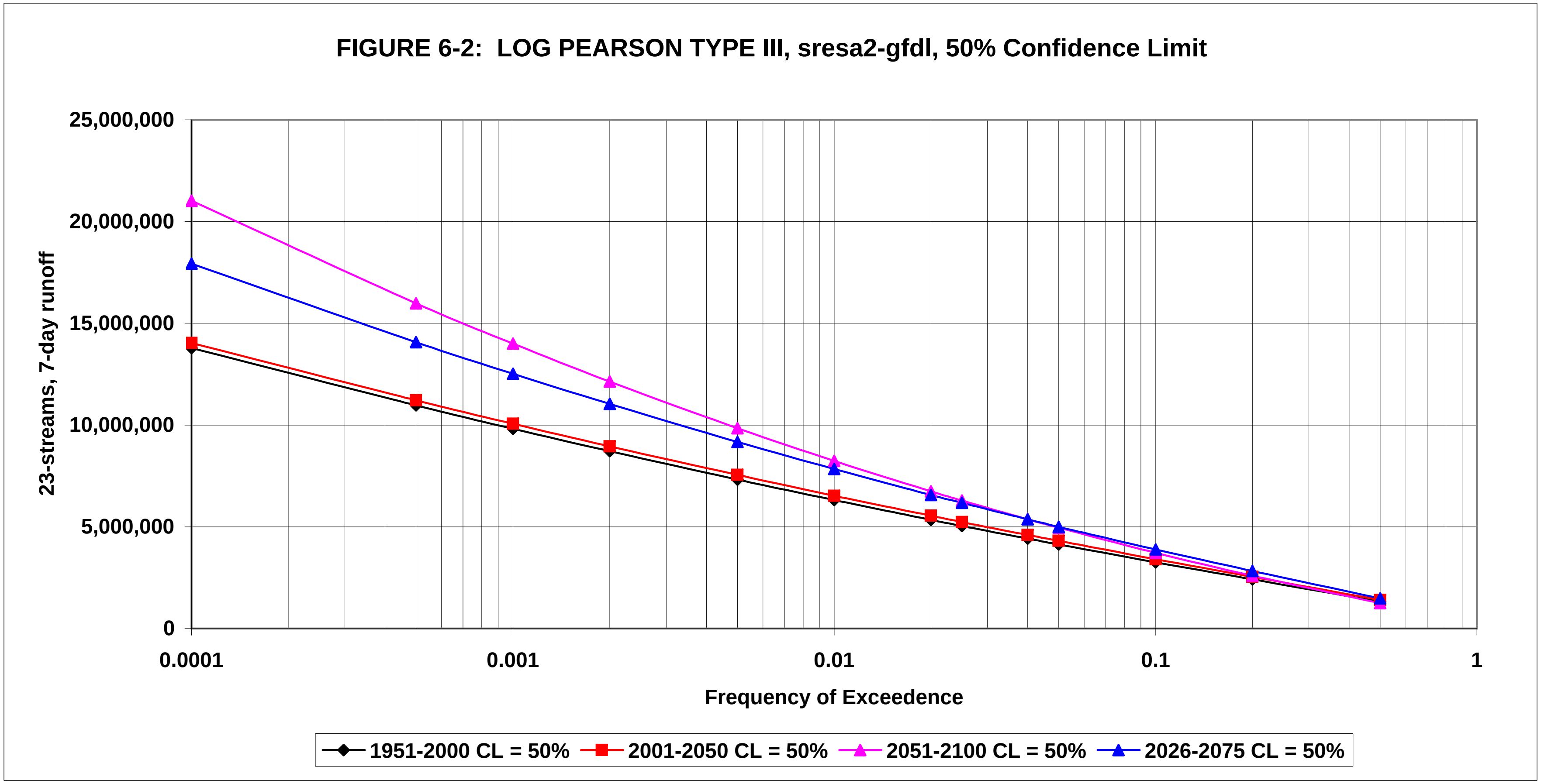


FIGURE 6-2: LOG PEARSON TYPE III, sresa2-gfdl, 50% Confidence Limit
25,000,000
20,000,000
15,000,000
10,000,000
5,000,000
0
23-streams, 7-day runoff
0.0001
0.001
0.01
0.1
1
Frequency of Exceedence
1951-2000 CL = 50%
2001-2050 CL = 50%
2051-2100 CL = 50%
2026-2075 CL = 50%

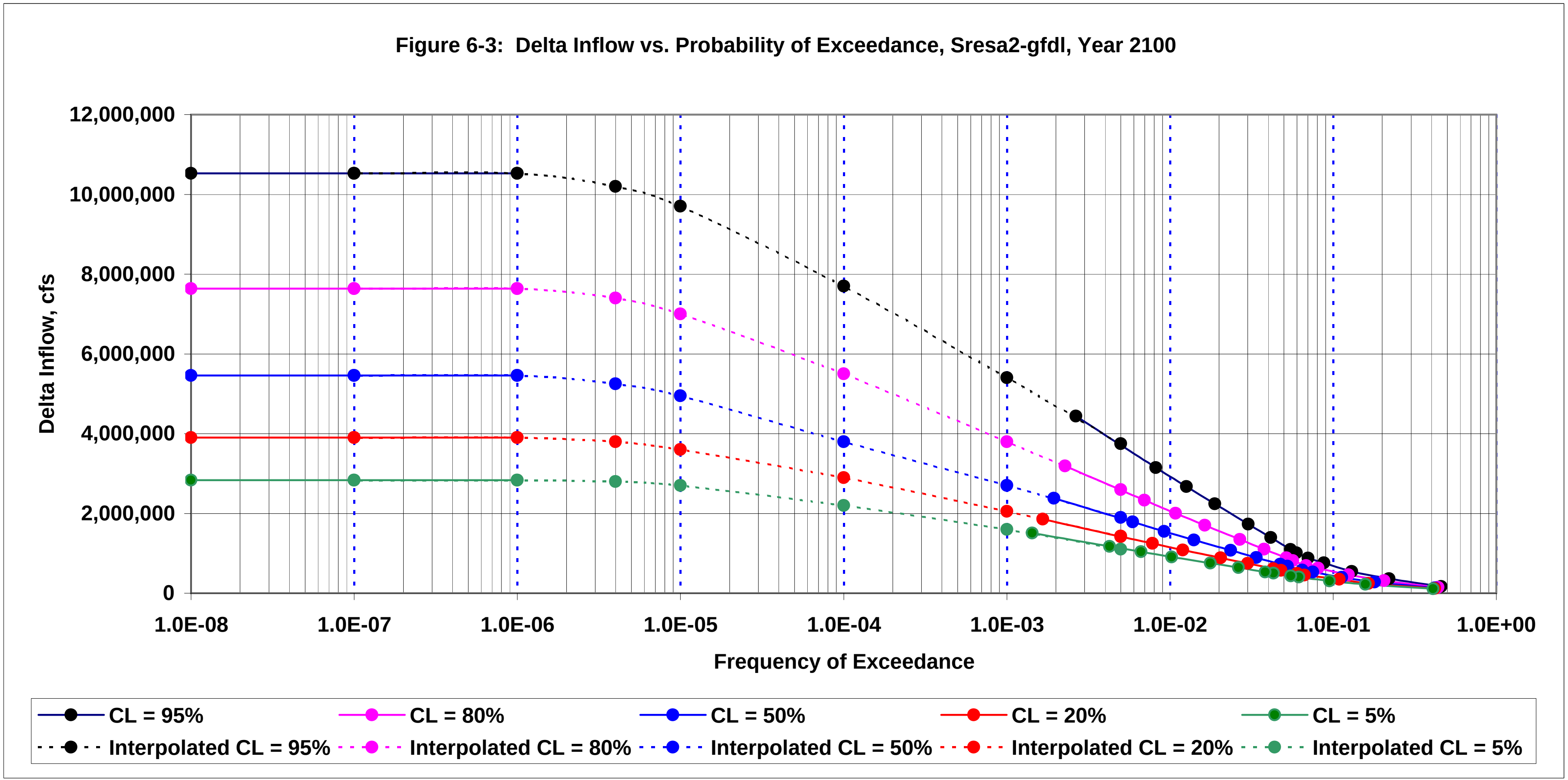


Figure 6-3: Delta Inflow vs. Probability of Exceedance, Sresa2-gfdl, Year 2100
Delta Inflow, cfs
12,000,000
10,000,000
8,000,000
6,000,000
4,000,000
2,000,000
0
1.0E-08
1.0E-07
1.0E-06
1.0E-05
1.0E-04
1.0E-03
1.0E-02
1.0E-01
1.0E+00
Frequency of Exceedance
CL = 95%
CL = 80%
CL = 50%
CL = 20%
CL = 5%
Interpolated CL = 95%
Interpolated CL = 80%
Interpolated CL = 50%
Interpolated CL = 20%
Interpolated CL = 5%

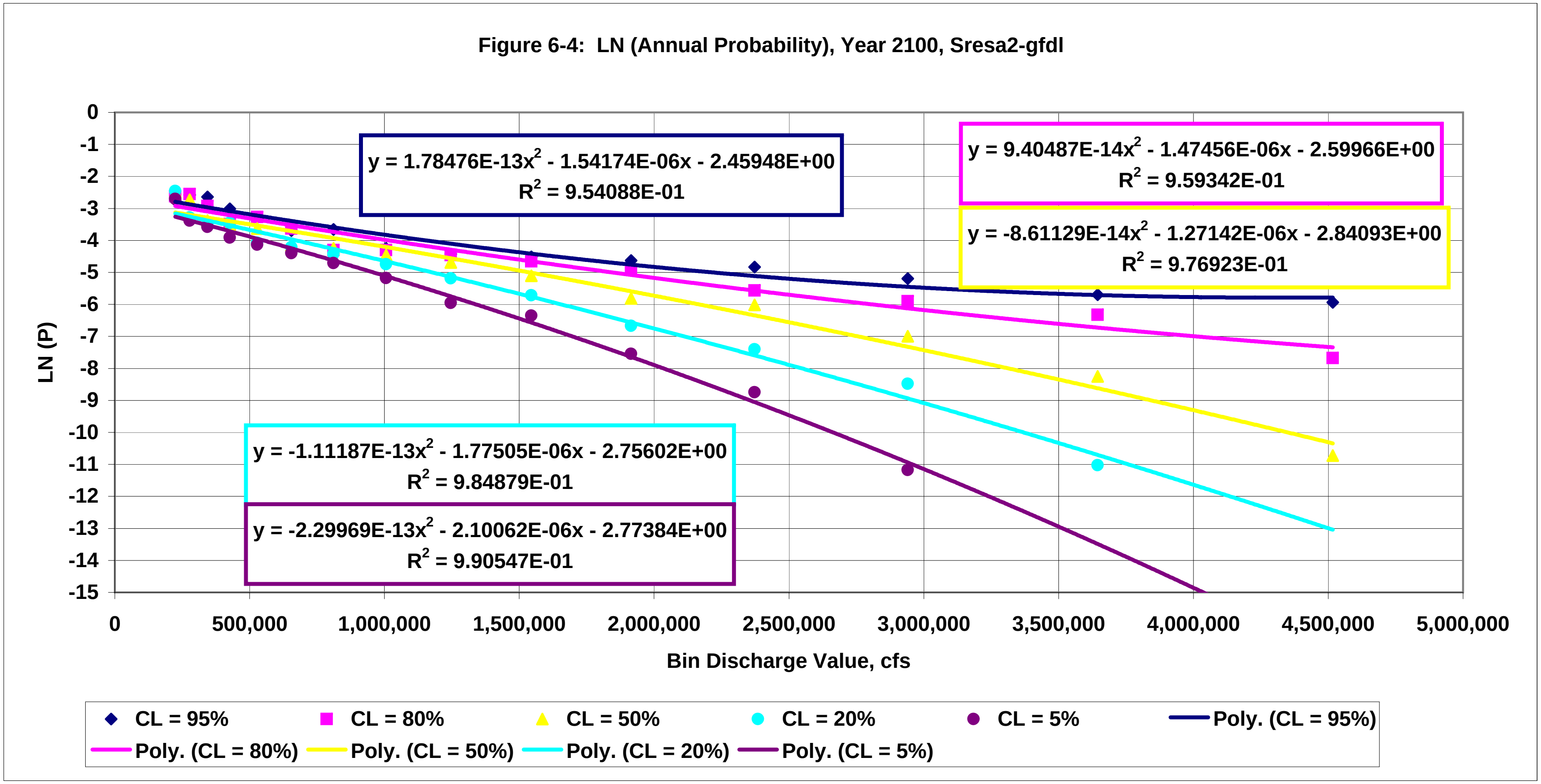


Figure 6-4: LN (Annual Probability), Year 2100, Sresa2-gfdl
y = 1.78476E-13x2 - 1.54174E-06x - 2.45948E+00
R2 = 9.54088E-01
y = 9.40487E-14x2 - 1.47456E-06x - 2.59966E+00
R2 = 9.59342E-01
y = -8.61129E-14x2 - 1.27142E-06x - 2.84093E+00
R2 = 9.76923E-01
y = -1.11187E-13x2 - 1.77505E-06x - 2.75602E+00
R2 = 9.84879E-01
y = -2.29969E-13x2 - 2.10062E-06x - 2.77384E+00
R2 = 9.90547E-01
LN (P)
0
-1
-2
-3
-4
-5
-6
-7
-8
-9
-10
-11
-12
-13
-14
-15
0
500,000
1,000,000
1,500,000
2,000,000
2,500,000
3,000,000
3,500,000
4,000,000
4,500,000
5,000,000
Bin Discharge Value, cfs
CL = 95%
CL = 80%
CL = 50%
CL = 20%
CL = 5%
Poly. (CL = 95%)
Poly. (CL = 80%)
Poly. (CL = 50%)
Poly. (CL = 20%)
Poly. (CL = 5%)

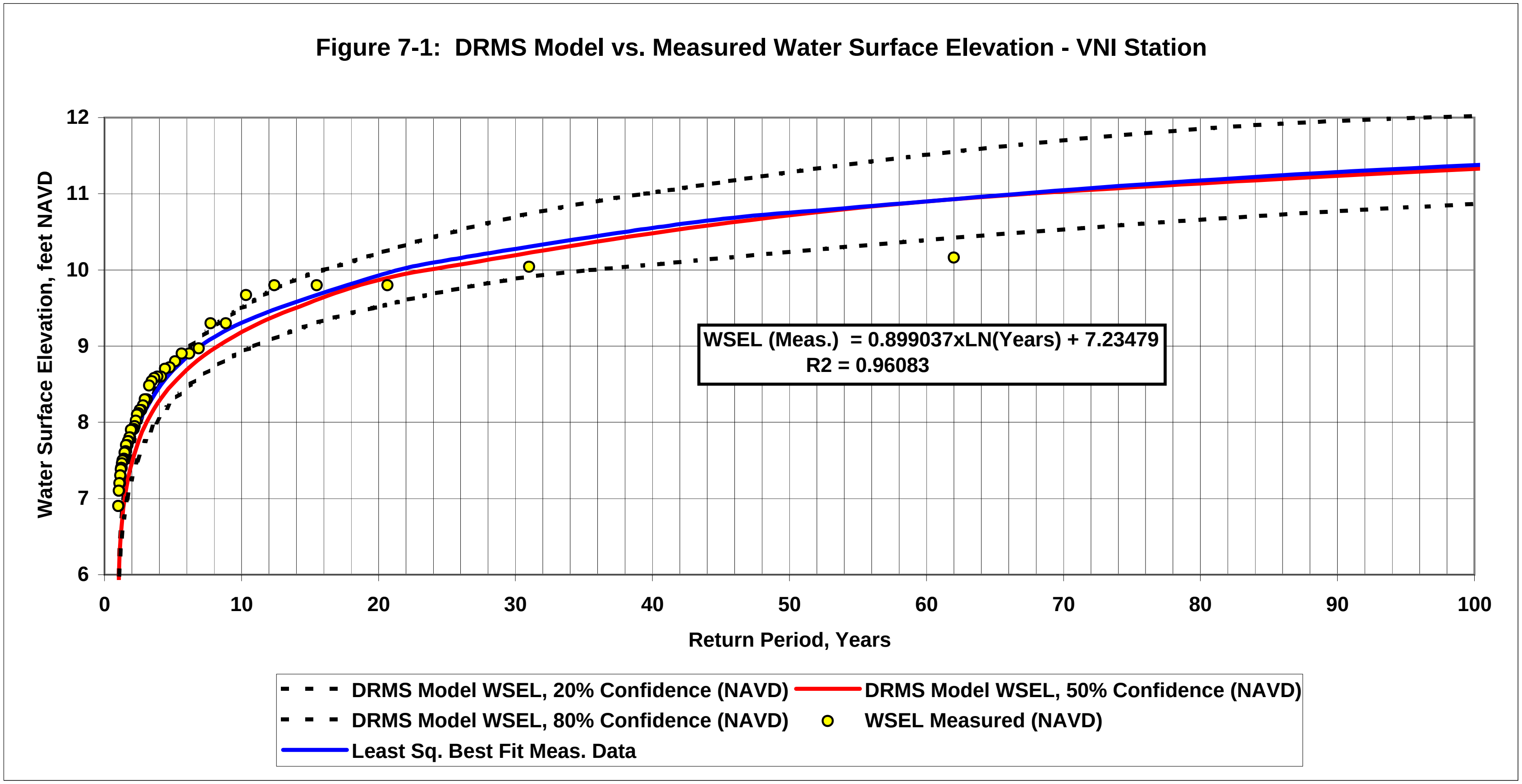


Figure 7-1: DRMS Model vs. Measured Water Surface Elevation - VNI Station
Water Surface Elevation, feet NAVD
12
11
10
9
8
7
6
0
10
20
30
40
50
60
70
80
90
100
Return Period, Years
WSEL (Meas.) = 0.899037xLN(Years) + 7.23479
R2 = 0.96083
DRMS Model WSEL, 20% Confidence (NAVD)
DRMS Model WSEL, 50% Confidence (NAVD)
DRMS Model WSEL, 80% Confidence (NAVD)
WSEL Measured (NAVD)
Least Sq. Best Fit Meas. Data

Appendix A
Results from Evaluation of Flood Stage Equations

Table A-1
Summary of Comparison Between Observed and Predicted Annual Peak Water Levels

Station Name	Station Identifier	Mean Error (feet)	Standard Deviation of Error (feet)	RMS Error (feet)
San Joaquin River at Antioch	ANH	0.0	0.2	0.23
Bacon Island at Old River	BAC	-0.05	0.39	0.34
Beldon Landing	BDL	-0.02	0.31	0.29
Benson's Ferry	BEN	0.37	1.55	1.54
Sacramento River at Freeport	FPL	0.25	0.71	0.73
Sacramento River at I Street Bridge	IST	0.30	0.51	0.56
Liberty Island - RD2068	LIR	-1.10	0.77	1.32
Yolo Bypass at Lisbon	LIS	0.16	0.83	0.80
Sacramento River at Mallard Island	MAL	0.04	0.20	0.19
Middle River At Howard Road Bridge	MHR	0.01	0.27	0.23
San Joaquin River At Mossdale Bridge	MSD	-0.37	0.60	0.66
Middle River At Tracy Blvd	MTB	0.07	0.24	0.22
Old River At Head	OH1	-0.47	0.83	0.89
Old River Near Tracy	OLD	-0.09	0.16	0.16
Old River At Byron	ORB	0.10	0.25	0.24
Roaring River	ROR	-0.05	0.35	0.34
Rough And Ready Island	RRI	0.00	0.20	0.17
San Joaquin R Blw Old R Near Lathrop	SJL	-0.12	0.11	0.15
Venice Island	VNI	0.06	0.34	0.33

Table A-2 Annual Peak Water Levels

Station	Year	Max Of Adjusted Max Daily	Max Of Predicted Daily	Predicted - Adjusted	Squared Error
ANH					
	1984	7.1	7.1	-0.1	0.0038
	1986	8.4	8.4	0.0	0.0009
	1989	6.2	6.4	0.2	0.0342
	1992	6.9	6.9	0.0	0.0002
	1993	7.3	7.1	-0.2	0.0437
	1995	8.1	7.7	-0.4	0.1590
	1996	7.3	7.1	-0.1	0.0151
	1997	7.8	8.2	0.4	0.1408
	1998	8.8	9.0	0.3	0.0752
	1999	6.4	6.5	0.0	0.0023
	2000	7.1	7.2	0.0	0.0009
	2001	6.1	6.3	0.2	0.0450
	2002	6.9	6.9	0.0	0.0004
	2003	6.4	6.8	0.4	0.1829
	2004	6.8	6.5	-0.3	0.0751
			Mean	0.0	0.05
			Standard Deviation	0.2	0.06
			RMS		0.23
BAC					
	2002	8.50	7.96	-0.54	0.2955
	2003	7.80	7.89	0.09	0.0090
	2004	7.62	8.00	0.38	0.1470
	2005	7.95	7.83	-0.12	0.0137
			Mean	-0.05	0.12
			Standard Dev.	0.39	0.14
			RMS		0.341
BDL					
	1998	7.06	7.40	0.34	0.11
	1999	7.16	7.31	0.15	0.02
	2000	8.09	7.95	-0.15	0.02
	2001	7.33	7.07	-0.26	0.07
	2002	7.71	7.59	-0.12	0.01
	2003	7.22	7.52	0.30	0.09
	2004	7.57	7.01	-0.56	0.31
	2005	7.39	7.52	0.13	0.02
			Mean	-0.02	0.08

Table A-2 Annual Peak Water Levels

Station	Year	Max Of Adjusted Max Daily	Max Of Predicted Daily	Predicted - Adjusted	Squared Error
			Standard Dev.	0.31	0.10
			RMS		0.29
BEN					
	1984	11.95	13.75	1.80	3.22
	1986	13.68	16.73	3.05	9.28
	1989	10.68	9.44	-1.24	1.53
	1993	13.19	12.56	-0.63	0.39
	1995	17.51	18.80	1.29	1.65
	1996	14.88	17.92	3.04	9.25
	1997	8.58	8.50	-0.08	0.01
	1998	13.82	14.96	1.14	1.30
	1999	15.23	16.67	1.44	2.09
	2000	15.14	15.08	-0.06	0.00
	2001	7.56	7.42	-0.14	0.02
	2002	10.57	9.47	-1.10	1.22
	2003	7.57	7.86	0.29	0.08
	2004	11.80	10.68	-1.12	1.24
	2005	13.90	11.80	-2.10	4.40
			Mean	0.37	2.38
			Standard Dev.	1.55	3.06
			RMS		1.54
DLC					
	2004	6.12	6.32	0.20	0.04
	2005	11.08	7.27	-3.82	14.57
FPT					
	1984	21.23	20.80	-0.43	0.19
	1986	27.46	28.64	1.18	1.39
	1989	18.78	17.88	-0.90	0.80
	1992	12.64	13.52	0.88	0.77
	1993	20.02	20.25	0.23	0.05
	1995	24.24	24.54	0.30	0.09
	1996	23.36	23.43	0.07	0.01
	1997	26.30	28.05	1.75	3.08
	1998	23.43	23.02	-0.41	0.17
	1999	21.60	20.92	-0.68	0.46
	2000	21.70	21.43	-0.27	0.08
	2001	12.35	13.29	0.94	0.88

Table A-2 Annual Peak Water Levels

Station	Year	Max Of Adjusted Max Daily	Max Of Predicted Daily	Predicted - Adjusted	Squared Error
	2002	16.80	17.24	0.44	0.20
	2003	16.81	16.92	0.11	0.01
	2004	19.06	19.45	0.39	0.15
	2005	14.66	15.02	0.36	0.13
			Mean	0.25	0.53
			Standard Dev.	0.71	0.79
			RMS		0.73
GCT					
	Not Available				
GSS					
	2004	12.30	12.24	-0.06	
	2005	12.86	12.60	-0.26	
IST					
	1999	27.78	27.43	-0.35	0.12
	2000	27.86	27.92	0.06	0.00
	2001	15.94	17.02	1.08	1.17
	2002	21.45	22.08	0.63	0.39
	2003	21.57	21.56	-0.01	0.00
	2004	24.47	24.88	0.41	0.17
			Mean	0.30	0.31
			Standard Dev.	0.51	0.45
			RMS		0.56
LIR					
	1998	9.09	8.48	-0.61	0.37
	1999	7.34	6.50	-0.84	0.70
	2000	8.55	6.78	-1.77	3.14
	2001	3.93	3.94	0.01	0.00
	2002	7.64	5.33	-2.31	5.35
	2003	5.2	5.07	-0.13	0.02
	2004	7.78	6.46	-1.32	1.75
	2005	9.11	7.62	-1.49	2.23
	2006	10.27	8.80	-1.47	2.17
			Mean	-1.10	1.75
			Standard Dev.	0.77	1.75
			RMS		1.32

Table A-2 Annual Peak Water Levels

Station	Year	Max Of Adjusted Max Daily	Max Of Predicted Daily	Predicted - Adjusted	Squared Error
LIS					
	1984	20.88	20.46	-0.42	0.18
	1986	27.53	29.05	1.52	2.31
	1993	18.19	16.97	-1.22	1.48
	1995	23.81	23.81	0.00	0.00
	1996	19.97	20.42	0.45	0.20
	1997	27.18	28.39	1.21	1.47
	1998	23.32	23.34	0.02	0.00
	1999	17.24	16.95	-0.29	0.08
	2000	18.36	18.50	0.14	0.02
			Mean	0.16	0.64
			Standard Dev.	0.83	0.87
			RMS		0.80
MAL					
	1989	6.30	6.55	0.24	0.06
	1993	7.34	7.27	-0.07	0.00
	1995	7.85	7.73	-0.12	0.02
	1996	7.41	7.30	-0.11	0.01
	1997	7.81	7.99	0.17	0.03
	1998	8.82	9.13	0.31	0.10
	1999	6.66	6.64	-0.02	0.00
	2000	7.29	7.33	0.04	0.00
	2001	6.33	6.51	0.17	0.03
	2002	7.15	7.11	-0.04	0.00
	2003	6.70	7.03	0.32	0.10
	2004	6.93	6.57	-0.36	0.13
	2005	6.96	6.88	-0.08	0.01
			Mean	0.04	0.04
			Standard Dev.	0.20	0.04
			RMS		0.19
MHR					
	2002	7.92	7.62	-0.30	0.09
	2003	7.33	7.64	0.31	0.09
	2004	7.79	7.92	0.13	0.02

Table A-2 Annual Peak Water Levels

Station	Year	Max Of Adjusted Max Daily	Max Of Predicted Daily	Predicted - Adjusted	Squared Error
	2005	8.50	8.39	-0.11	0.01
			Mean	0.01	0.05
			Standard Dev.	0.27	0.04
			RMS		0.23
MRZ					
	Not Available				
MSD					
	2000	11.74	11.32	-0.42	0.18
	2001	5.71	5.46	-0.25	0.06
	2002	5.53	5.55	0.02	0.00
	2003	5.62	4.25	-1.37	1.88
	2004	5.39	5.56	0.17	0.03
			Mean	-0.37	0.43
			Standard Dev.	0.60	0.81
			RMS		0.66
MTB					
	2000	8.02	8.26	0.24	0.06
	2002	6.61	6.67	0.06	0.00
	2003	7.03	7.38	0.35	0.12
	2004	7.46	7.22	-0.24	0.06
	2005	7.87	7.80	-0.07	0.01
			Mean	0.07	0.05
			Standard Dev.	0.24	0.05
			RMS		0.22
OBD					
	Not Available				
OH1					
	2000	10.96	8.83	-2.13	4.55
	2001	4.75	4.63	-0.12	0.01
	2002	4.87	4.68	-0.19	0.04
	2003	4.29	4.22	-0.07	0.00
	2004	4.78	4.81	0.03	0.00
	2005	8.57	8.25	-0.32	0.10
			Mean	-0.47	0.79
			Standard Dev.	0.83	1.85

Table A-2 Annual Peak Water Levels

Station	Year	Max Of Adjusted Max Daily	Max Of Predicted Daily	Predicted - Adjusted	Squared Error
			RMS		0.89
OLD					
	2002	6.94	6.79	-0.15	0.02
	2003	6.66	6.55	-0.11	0.01
	2004	7.01	7.14	0.13	0.02
	2005	8.17	7.93	-0.24	0.06
			Mean	-0.09	0.03
			Standard Dev.	0.16	0.02
			RMS		0.16
ORB					
	2001	6.52	6.77	0.25	0.06
	2002	7.14	7.12	-0.02	0.00
	2003	6.77	7.16	0.39	0.15
	2004	7.63	7.75	0.12	0.01
	2005	8.12	7.87	-0.25	0.06
			Mean	0.10	0.06
			Standard Dev.	0.25	0.06
			RMS		0.24
ROR					
	1993	7.57	7.39	-0.18	0.03
	1995	7.73	7.99	0.27	0.07
	1996	7.48	7.50	0.03	0.00
	1997	7.13	7.40	0.27	0.07
	1998	9.04	9.48	0.44	0.20
	1999	7.06	6.52	-0.53	0.28
	2000	8.05	7.59	-0.46	0.21
	2002	7.17	6.67	-0.50	0.25
	2003	7.04	7.35	0.31	0.09
	2004	7.13	6.91	-0.22	0.05
	2005	7.07	7.09	0.02	0.00
			Mean	-0.05	0.11
			Standard Dev.	0.35	0.10
			RMS		0.34

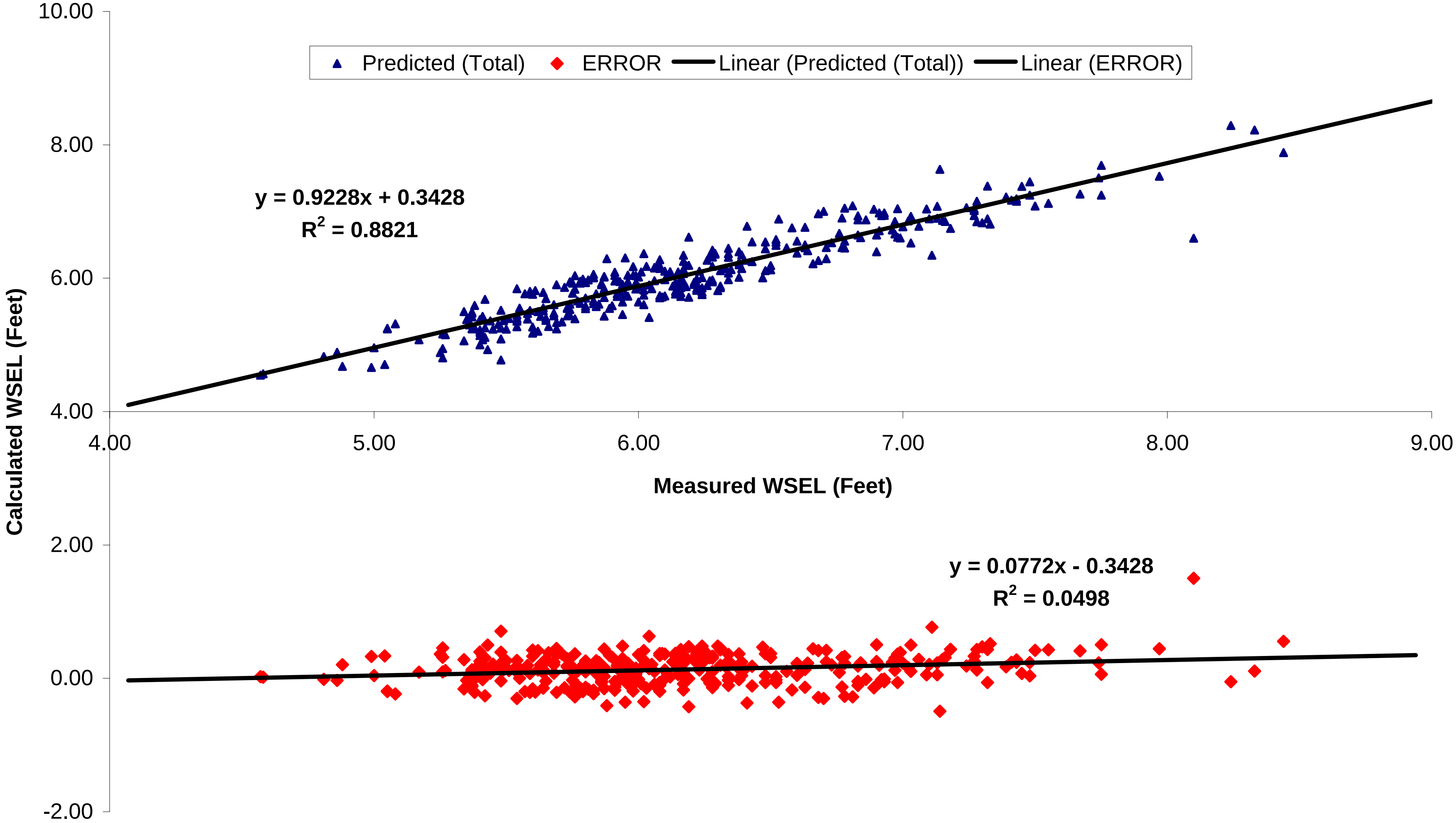
Table A-2 Annual Peak Water Levels

Station	Year	Max Of Adjusted Max Daily	Max Of Predicted Daily	Predicted - Adjusted	Squared Error
RRI					
	2002	7.55	7.41	-0.14	0.02
	2003	7.07	7.33	0.26	0.07
	2004	7.23	7.28	0.05	0.00
	2005	7.68	7.53	-0.15	0.02
			Mean	0.00	0.03
			Standard Dev.	0.20	0.03
			RMS		0.17
RSL					
	Not Available				
SDC					
	2004	11.57	11.27	-0.30	
	2005	11.86	11.50	-0.36	
SJG					
	2004	7.41	7.31	-0.10	
	2005	7.95	7.90	-0.05	
SJL					
	2002	7.85	7.81	-0.04	0.00
	2003	7.84	7.65	-0.19	0.04
	2004	7.72	7.72	0.00	0.00
	2005	11.65	11.42	-0.23	0.05
			Mean	-0.12	0.02
			Standard Dev.	0.11	0.03
			RMS		0.15
SJR					
	Not Available				
SDR					
	Not Available				
SRV					
	2006	7.47	7.45	-0.02	

Table A-2 Annual Peak Water Levels

Station	Year	Max Of Adjusted Max Daily	Max Of Predicted Daily	Predicted - Adjusted	Squared Error
SSS					
	2004	13.09	12.98	-0.11	
	2005	13.44	13.02	-0.42	
VNI					
	1986	9.67	9.72	0.05	0.00
	1993	8.02	7.98	-0.04	0.00
	1995	8.72	9.16	0.44	0.19
	1996	8.45	8.31	-0.14	0.02
	1997	8.97	8.86	-0.11	0.01
	1998	10.16	10.65	0.49	0.24
	1999	7.95	7.35	-0.60	0.36
	2000	8.54	8.38	-0.16	0.02
	2002	6.88	7.16	0.28	0.08
	2003	7.23	7.82	0.59	0.35
	2004	7.71	7.49	-0.22	0.05
	2005	7.72	7.84	0.12	0.02
			Mean	0.06	0.11
			Standard Dev.	0.34	0.14
			RMS		0.33

Figure A-1
ANTIOCH (ANH)
Measured Stage vs. Calculated Stage and Error
Total Flows Over 57,000 cfs



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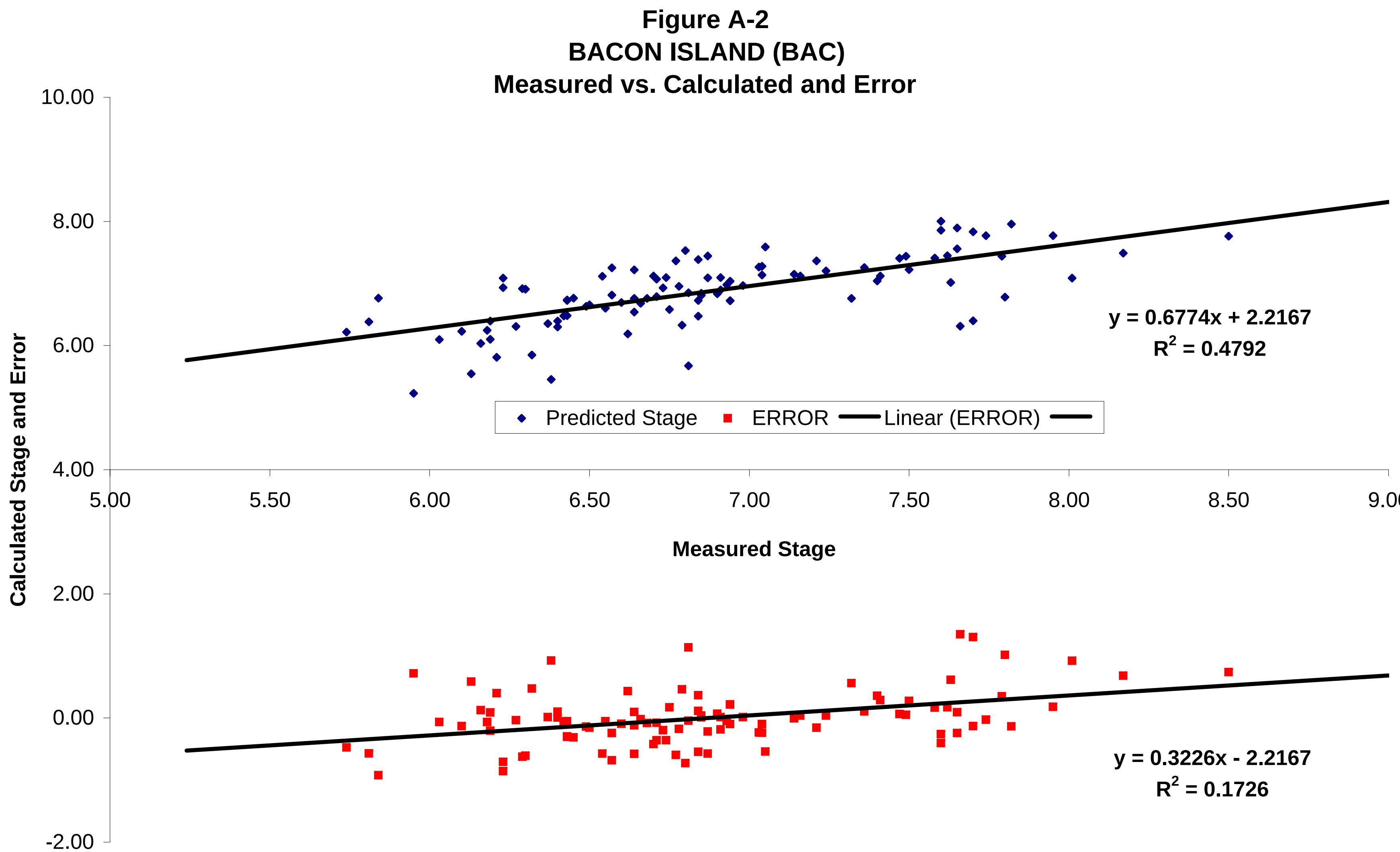
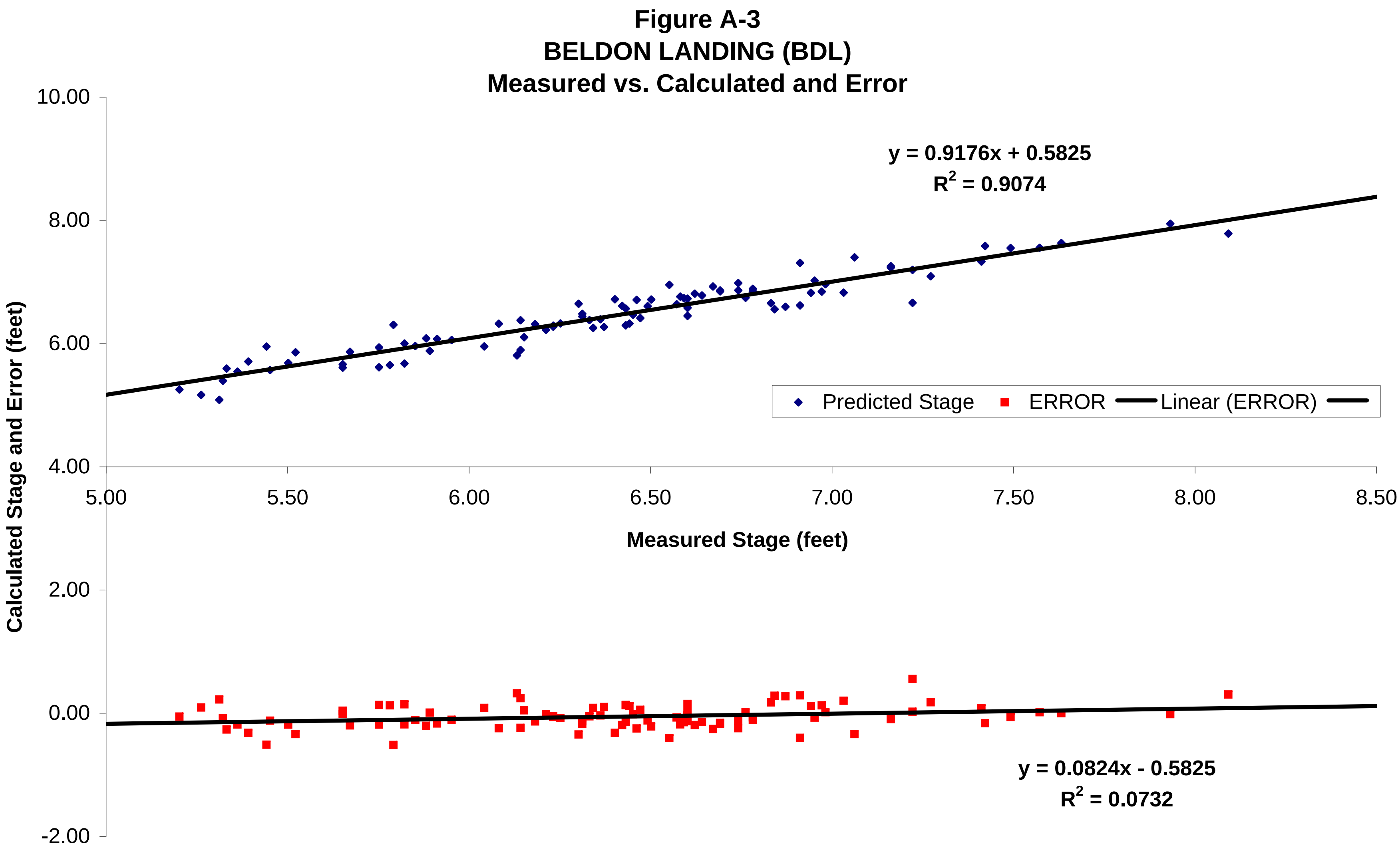


Figure A-2
BACON ISLAND (BAC)
Measured vs. Calculated and Error
Calculated Stage and Error
10.00
8.00
6.00
4.00
2.00
0.00
-2.00
5.00
5.50
6.00
6.50
7.00
7.50
8.00
8.50
9.00
Measured Stage
Predicted Stage
ERROR
Linear (ERROR)
y = 0.6774x + 2.2167
R^2 = 0.4792
y = 0.3226x - 2.2167
R^2 = 0.1726



Y:\DRMS\Phase 1 - Post IRP\TMs & Reports\Flood Hazard\Appendix A figures\Figure A-3 BDL_Best 03-04-08 Meas vs Calc and Error

Figure A-4
BENSON'S FERRY (BEN)
Measured vs. Calculated and Error

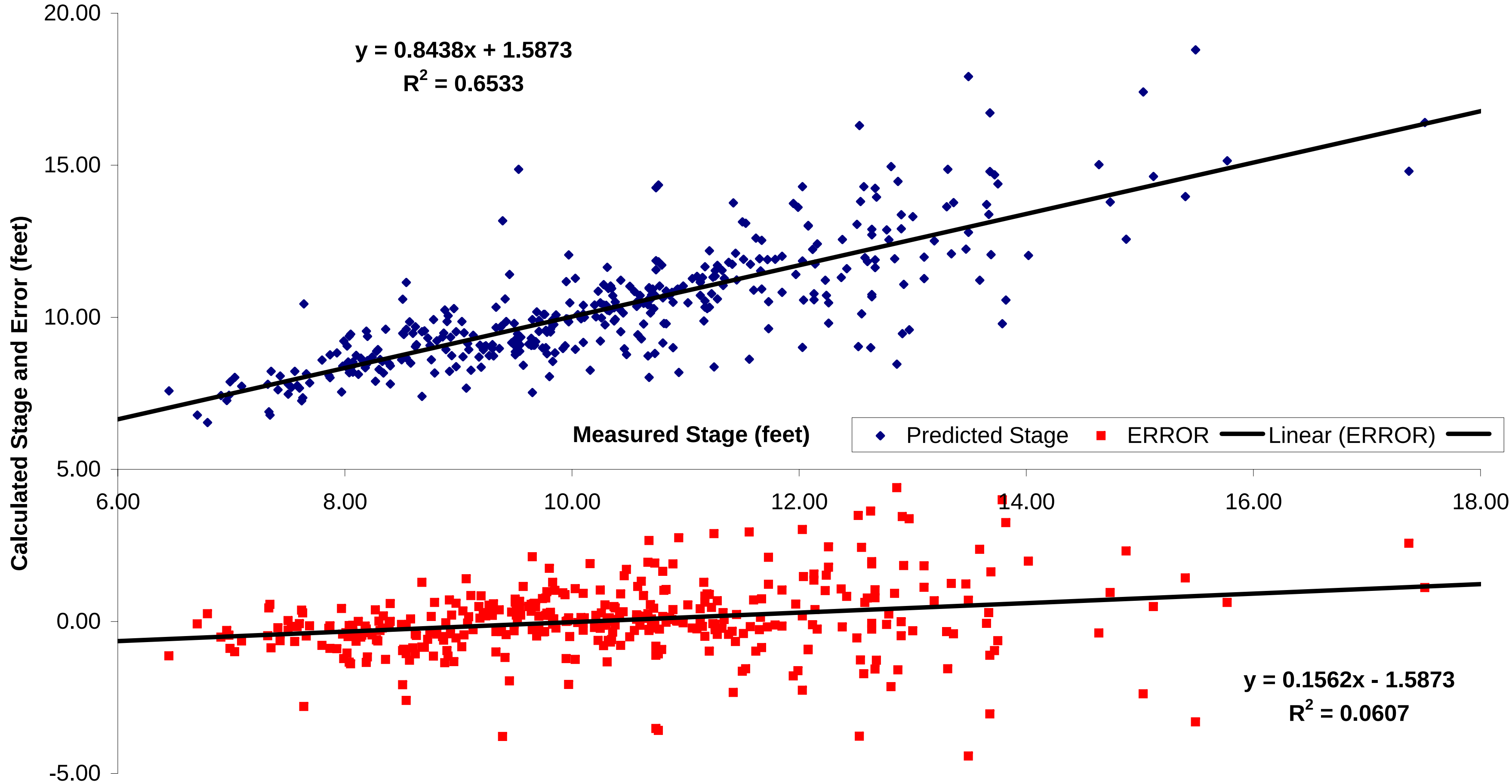


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Figure A-5
DELTA CROSS CHANNEL (DLC)
Measured vs. Calculated and Error

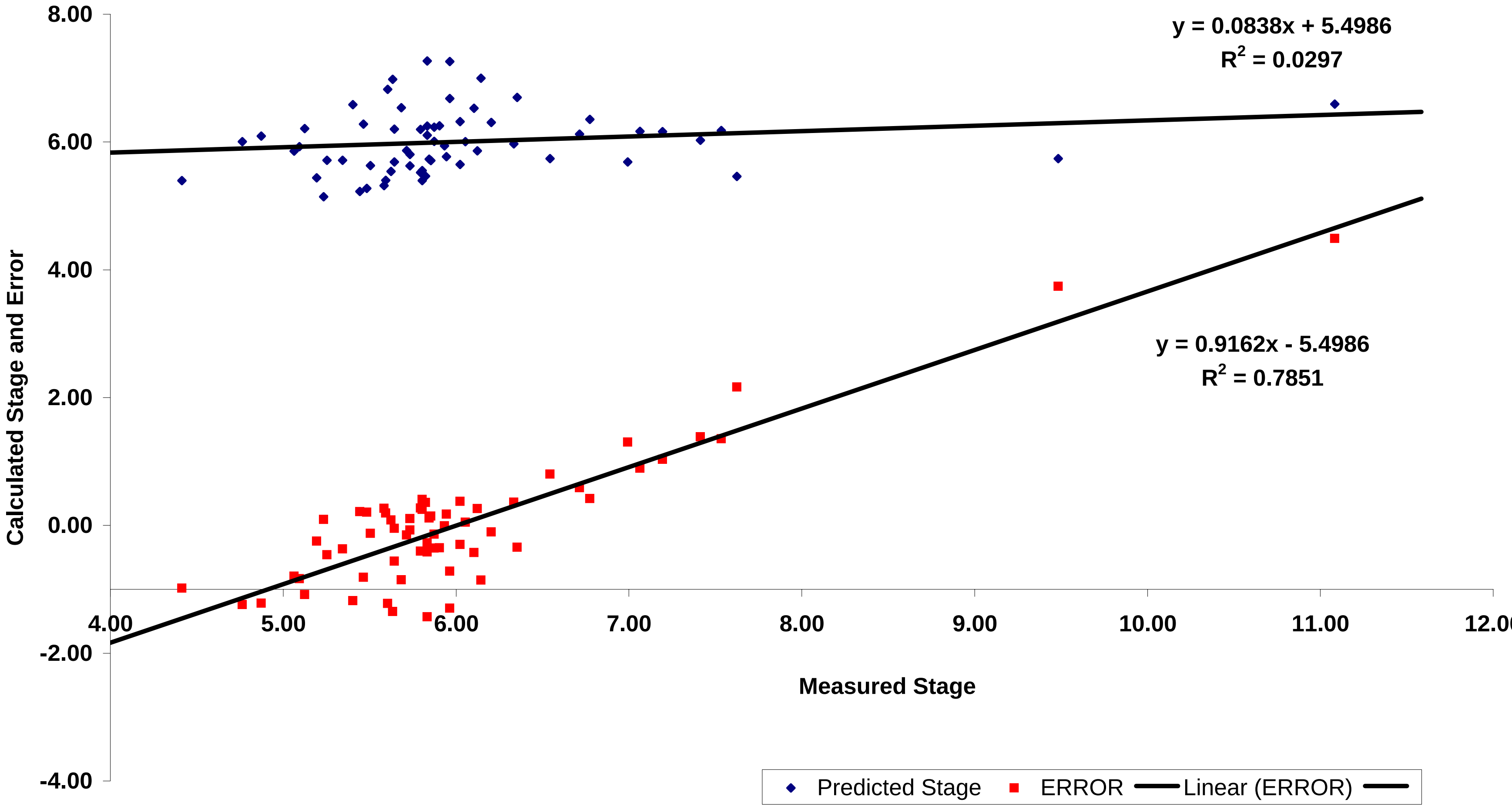

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Figure A-6
STAGE ON THE SACRAMENTO RIVER NEAR FREEPORT (FPT)
Measured vs. Calculated Stage and Error in Prediction

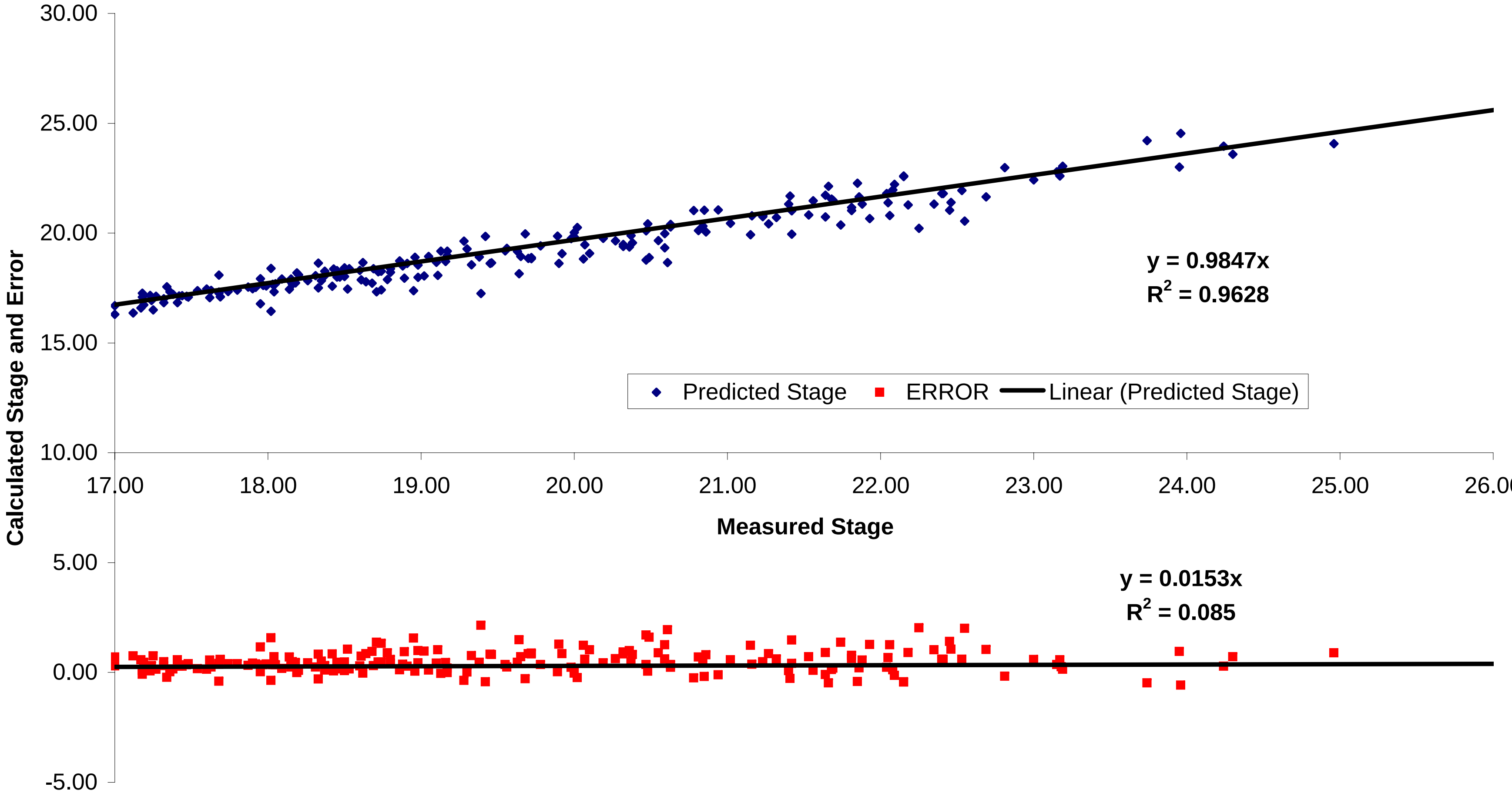

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Figure A-7
GEORGIANA SLOUGH AT SACRAMENTO RIVER (GSS)
Measured vs. Calculated and Error

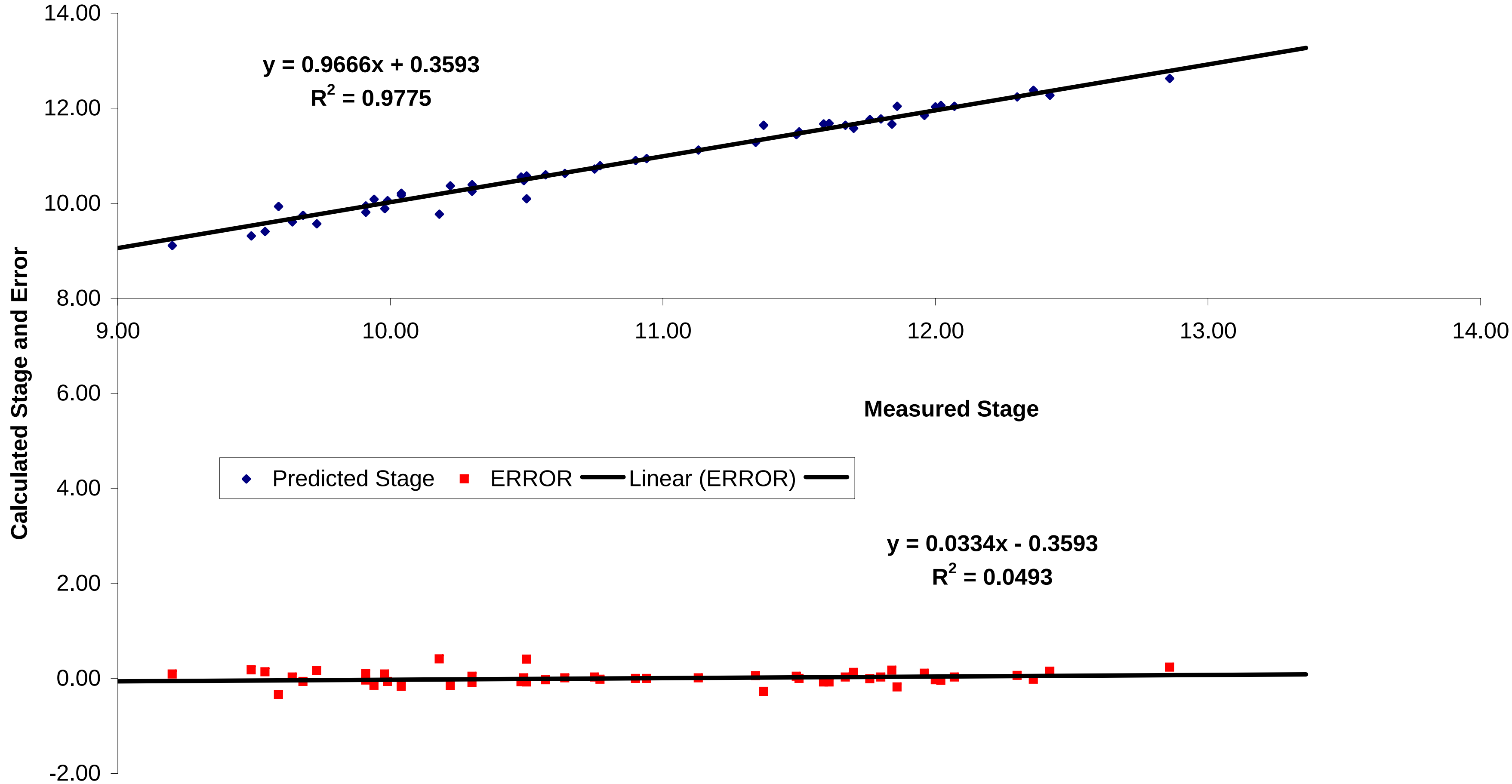

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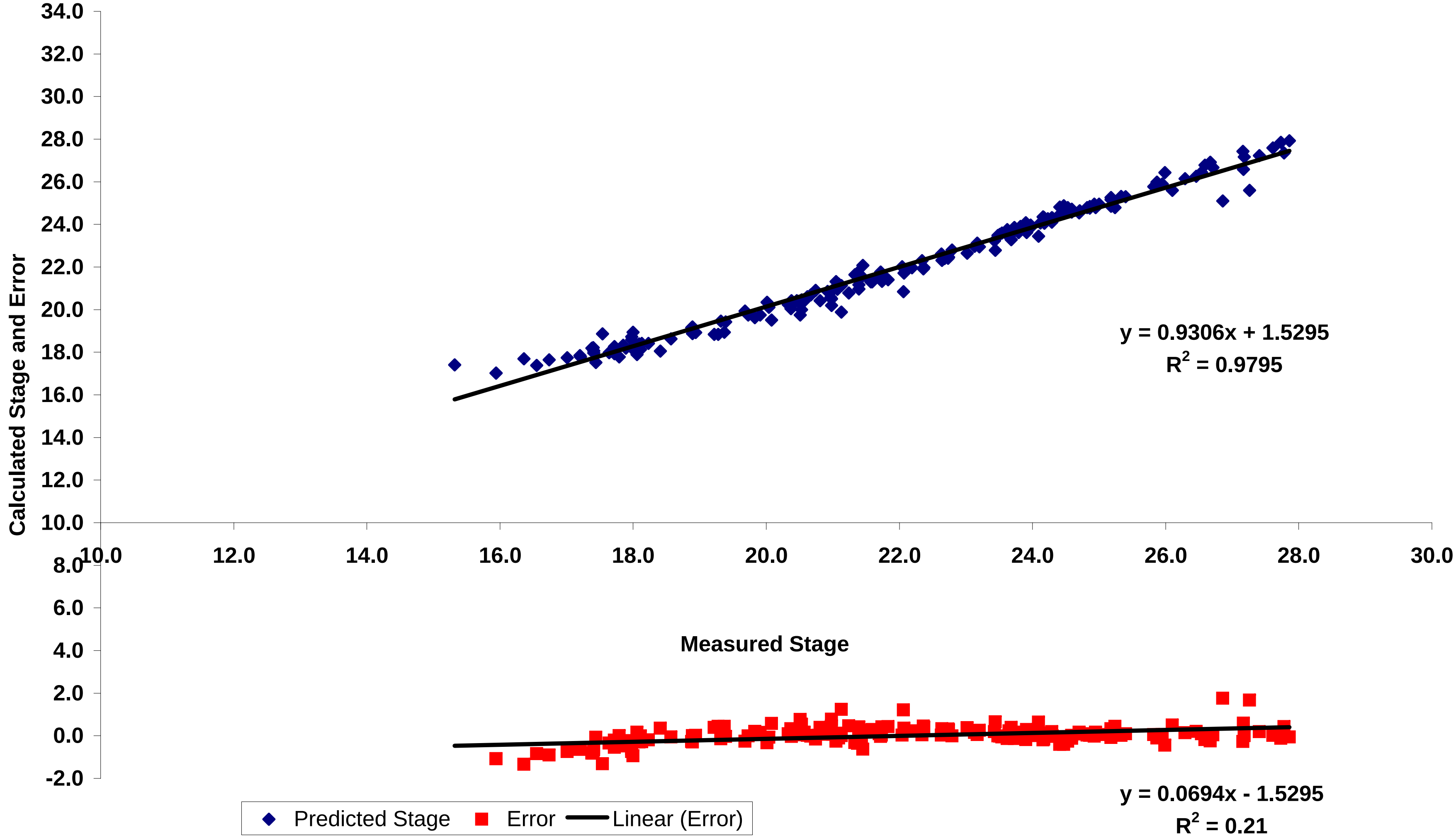
Figure A-8
I STREET IN SACRAMENTO (IST)
Measured vs. Calculated and Error



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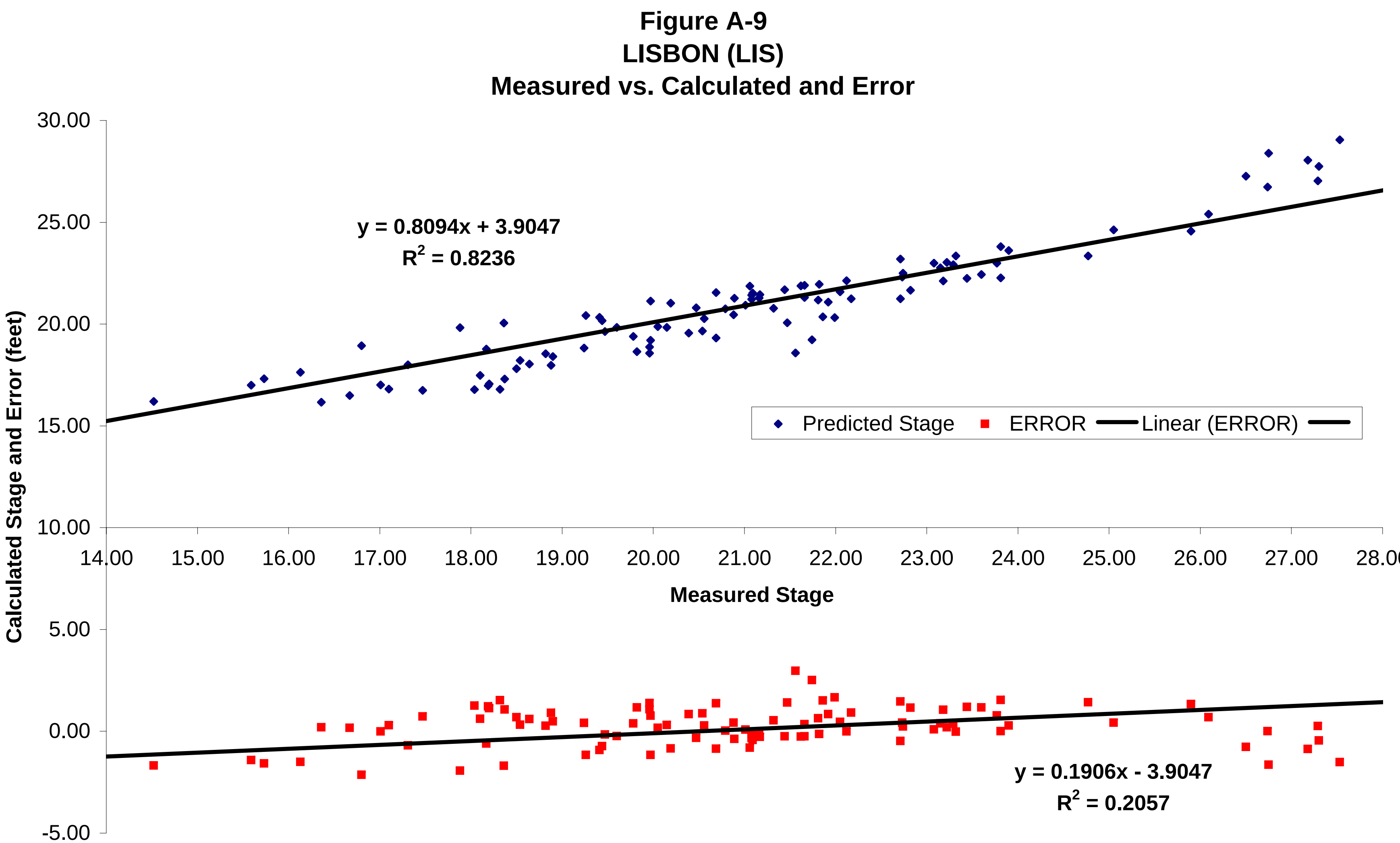

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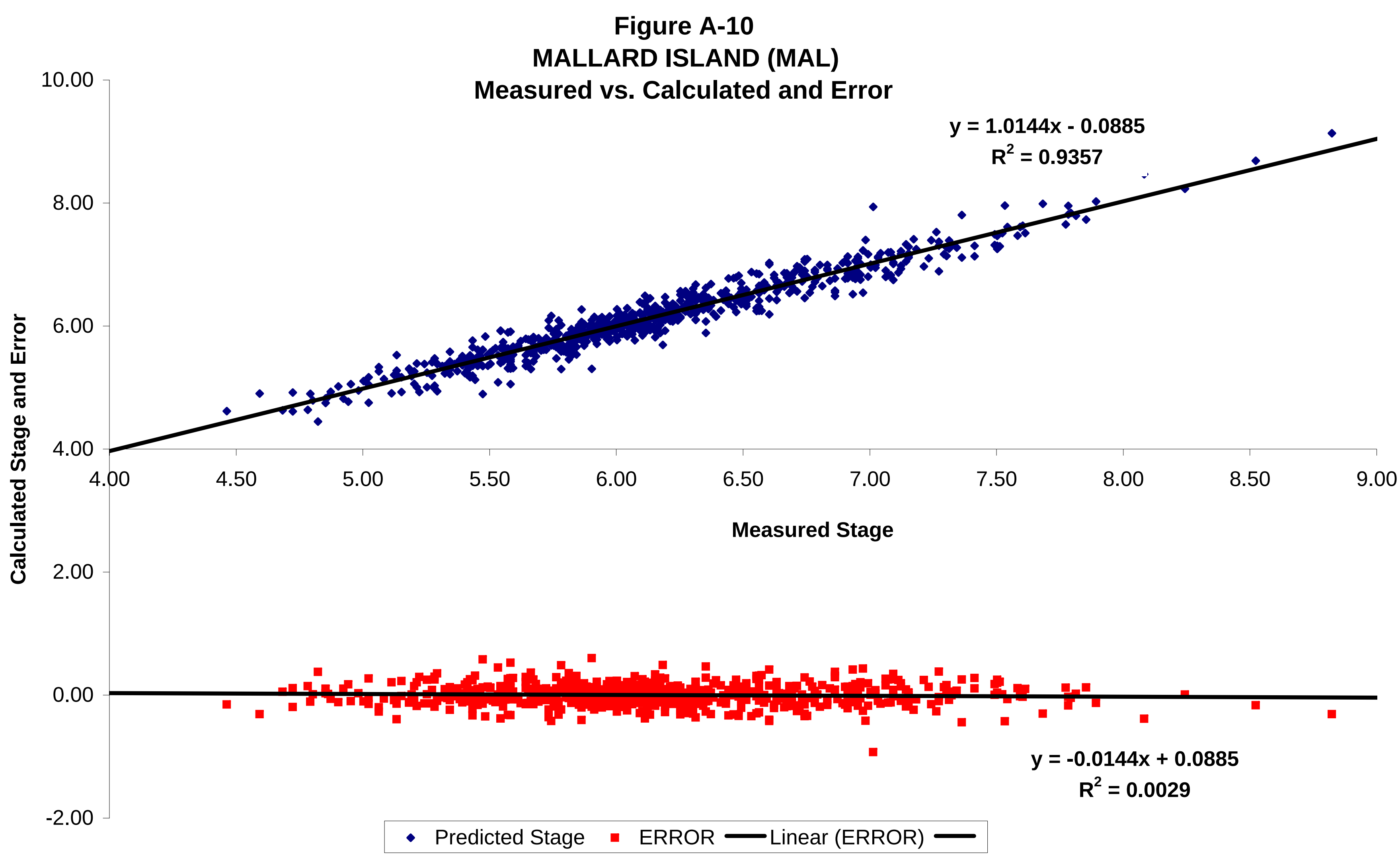

Y:\DRMS\Phase 1 - Post IRP\TMs & Reports\Flood Hazard\Appendix A figures\Figure A-10 MAL_Best 03-04-08 Meas vs Calc and Error

Figure A-11
MIDDLE RIVER AT HOWARD ROAD BRIDGE (MHR)
Measured vs. Calculated and Error

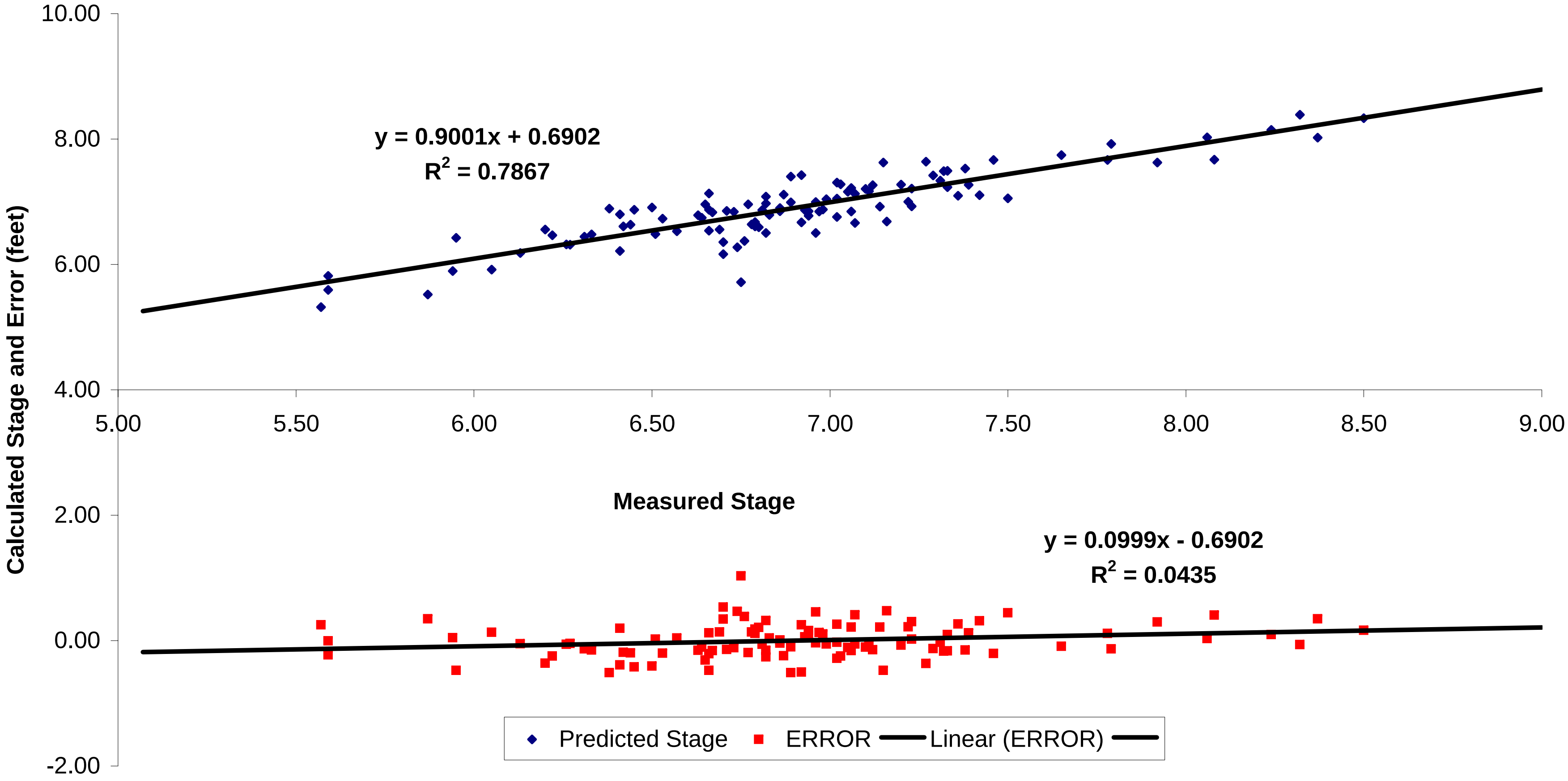

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Figure A-12
SAN JOAQUIN RIVER AT MOSSDALE BRIDGE (MSD)
Measured vs. Calculated and Error

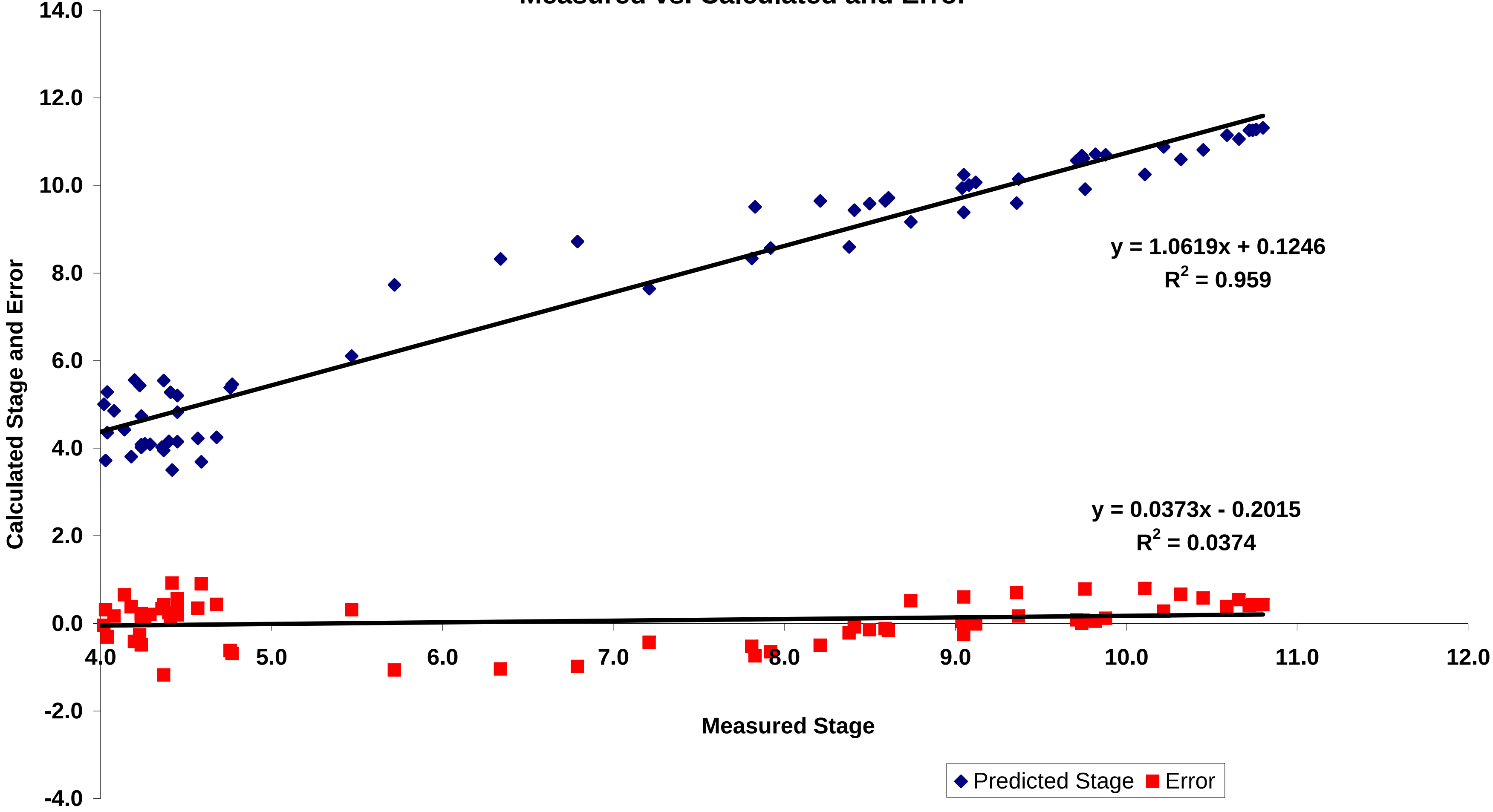

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Figure A-13
MIDDLE RIVER AT TRACY BLVD (MTB)
Measured vs. Calculated and Error

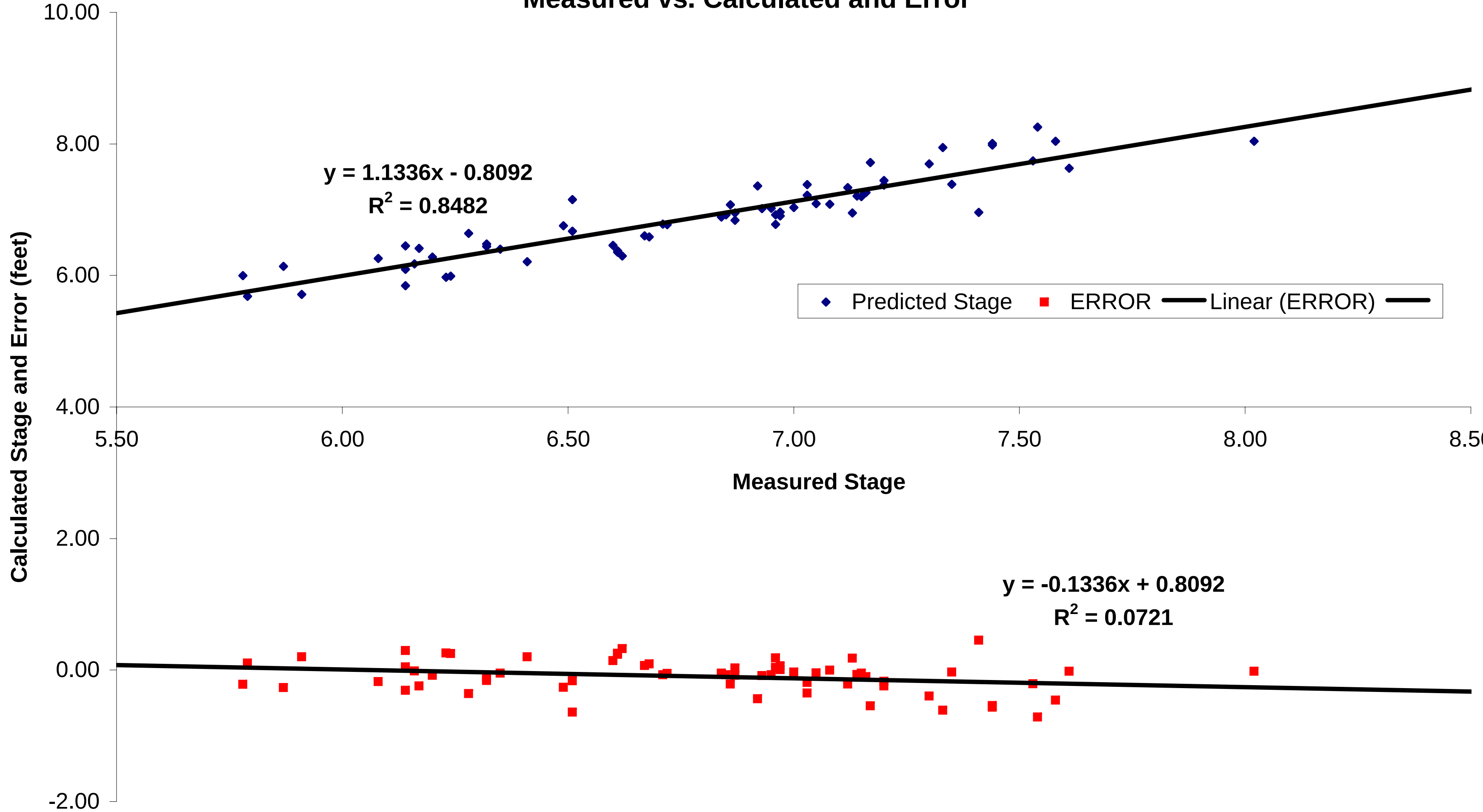


Figure A-14
OLD RIVER NEAR TRACY (OLD)
Measured vs. Calculated and Error

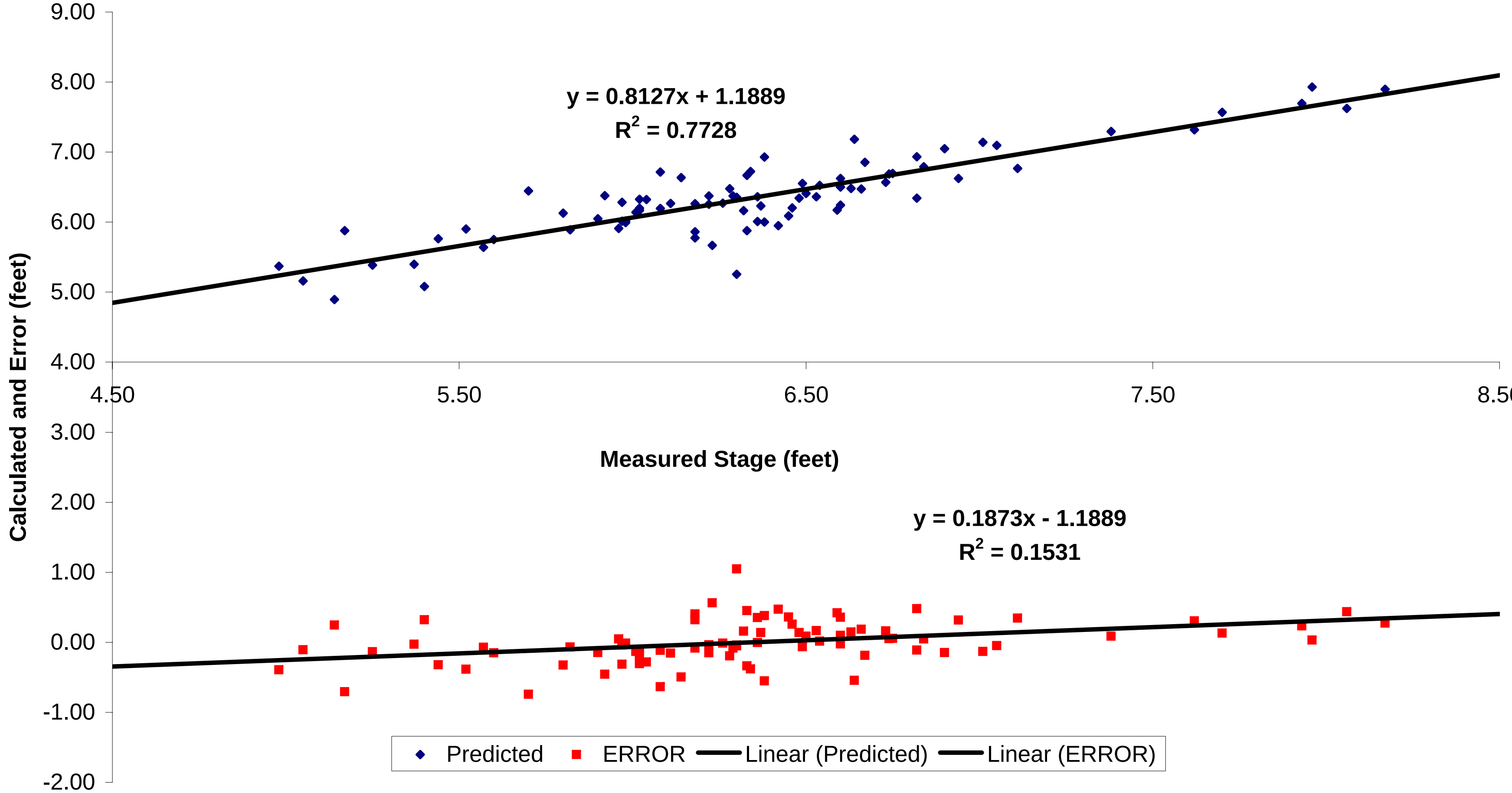
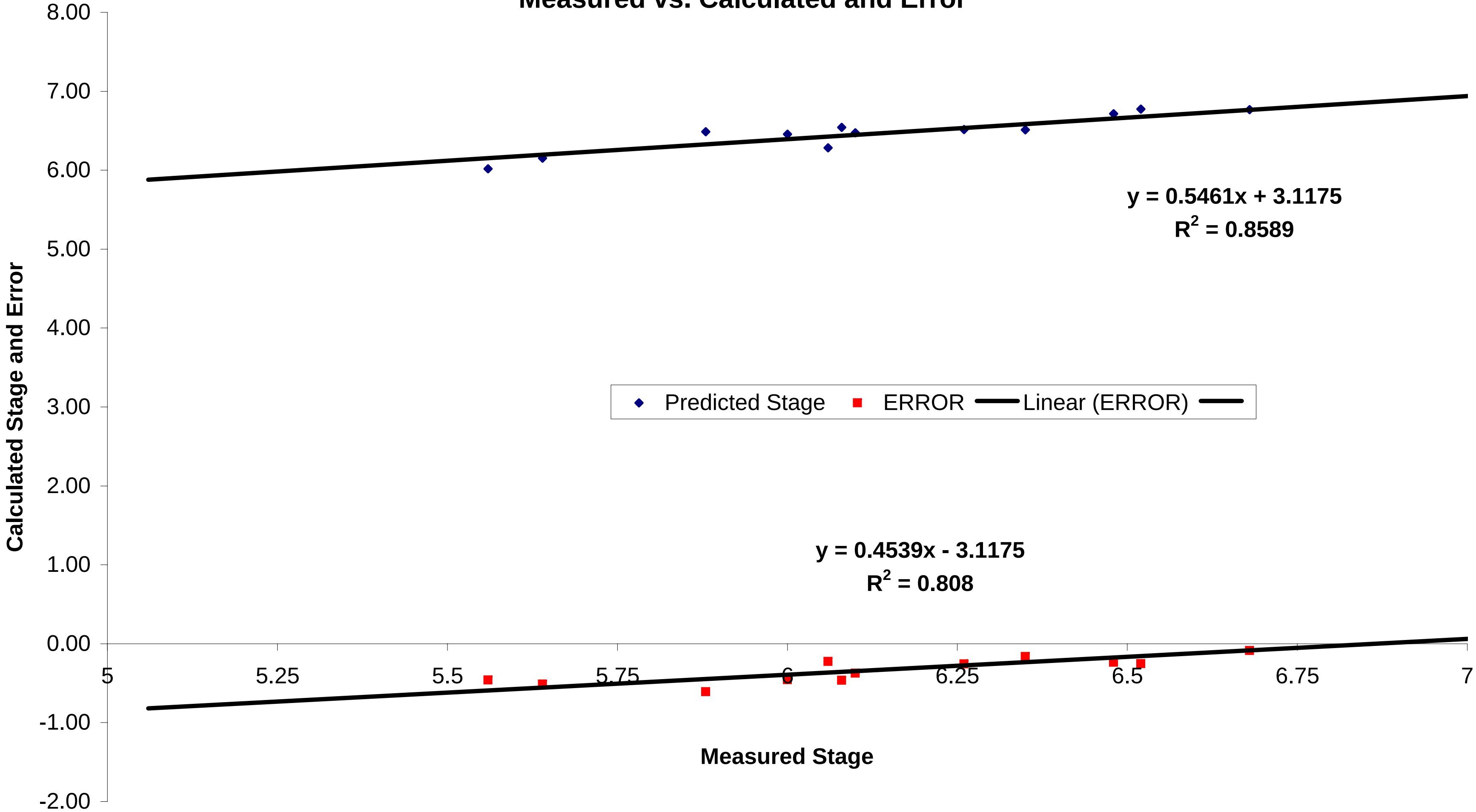


Figure A-15
OLD RIVER AT BYRON (ORB)
Measured vs. Calculated and Error



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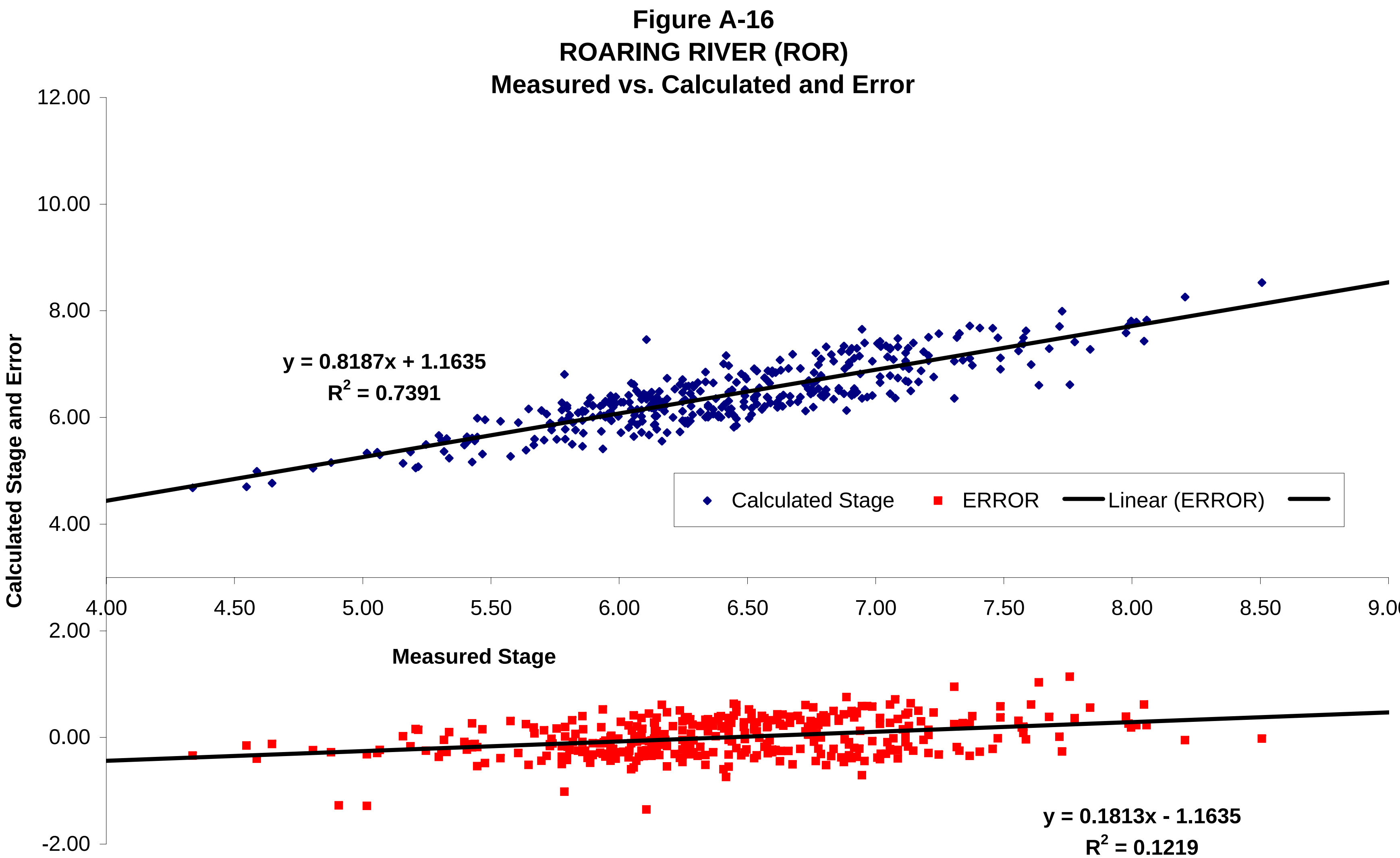

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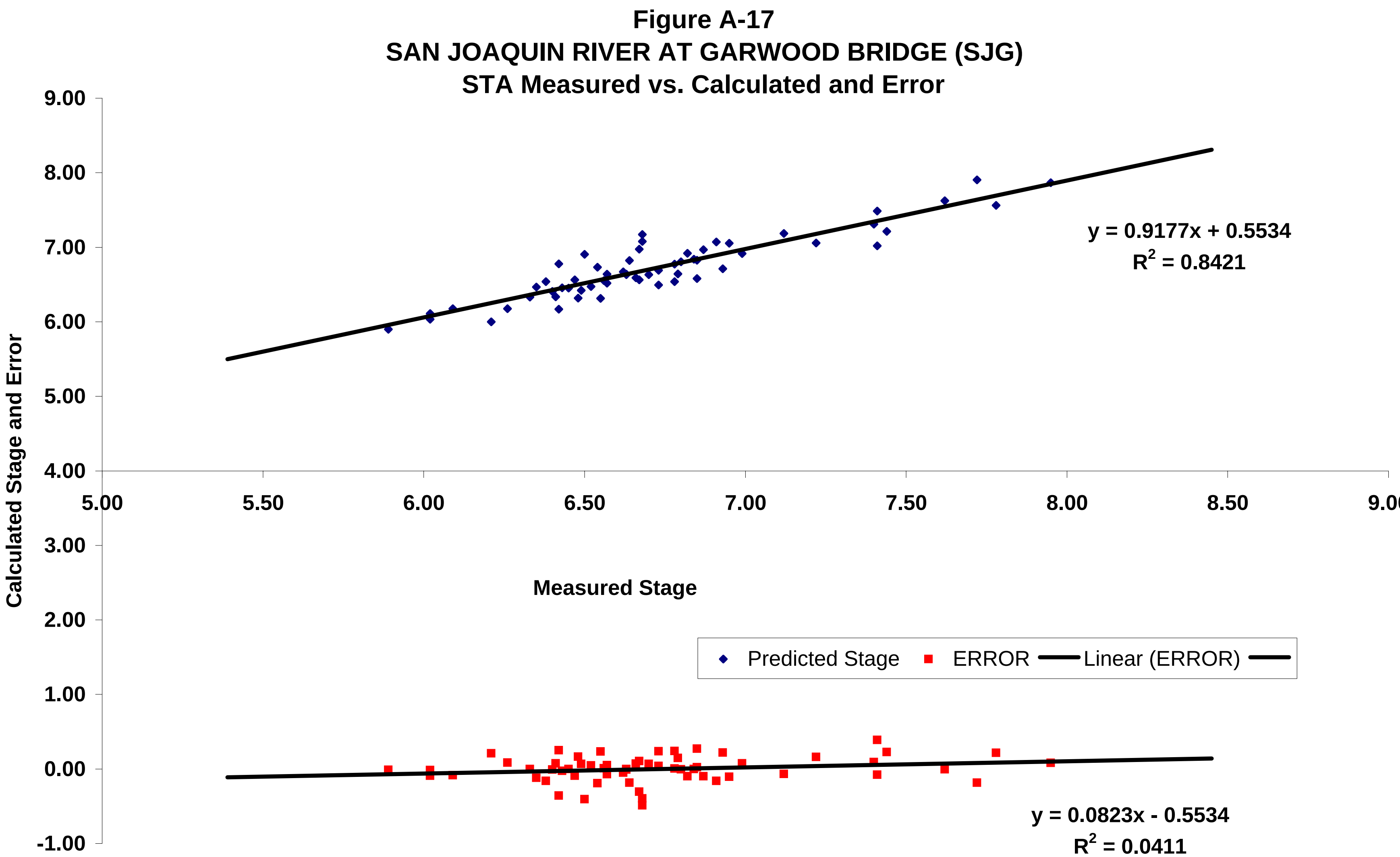

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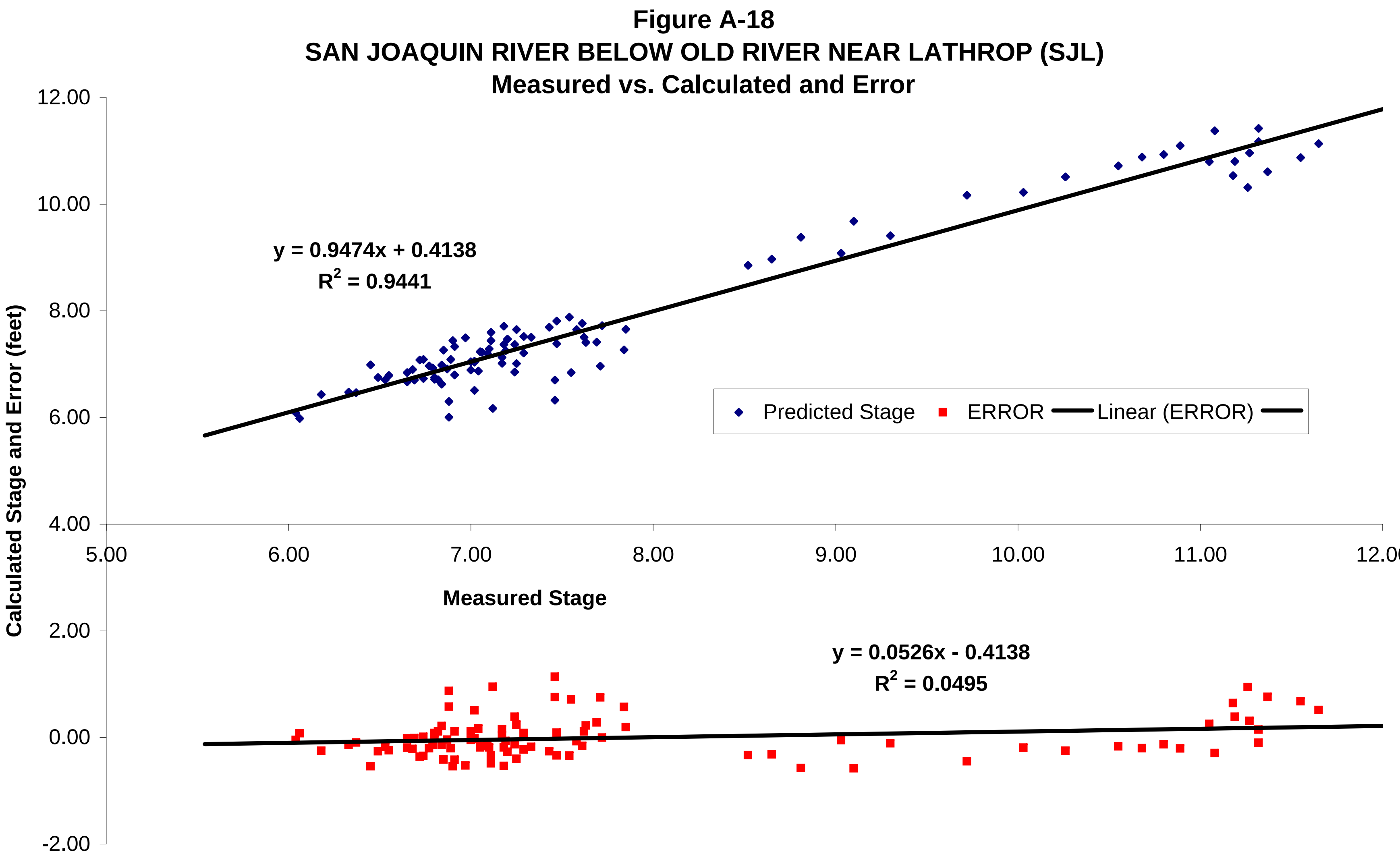

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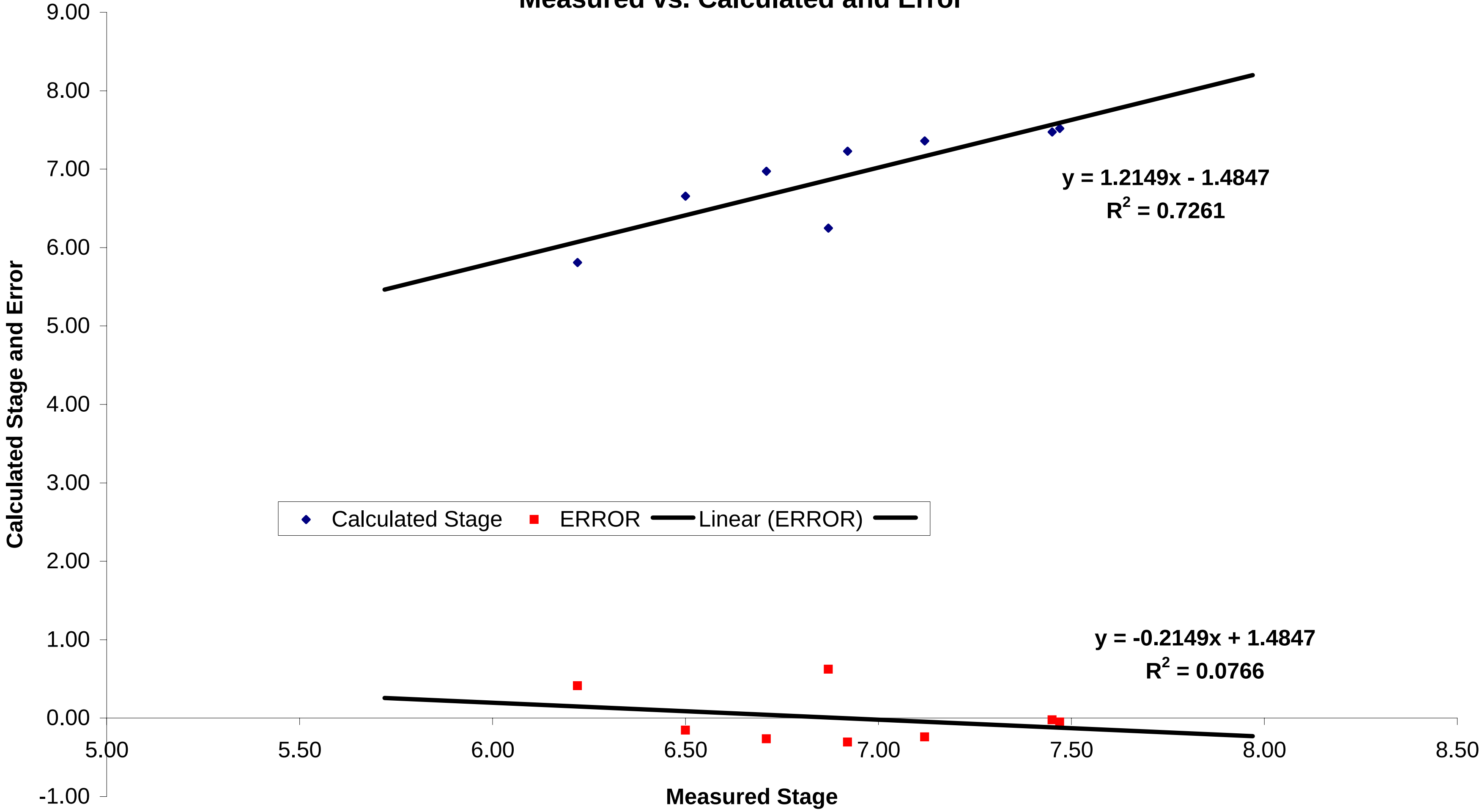
Figure A-19
SACRAMENTO RIVER AT RIO VISTA (SRV)
Measured vs. Calculated and Error



Y:\DRMS\Phase 1 - Post IRP\TMs & Reports\Flood Hazard\Appendix A figures\Figure A-19 SRV_Best 03-04-08 Meas vs Calc and Error

Figure A-20
STEAMBOAT SLOUGH BETWEEN SACRAMENTO RIVER AND SUTTER SLOUGH (SSS)
Measured vs. Calculated and Error

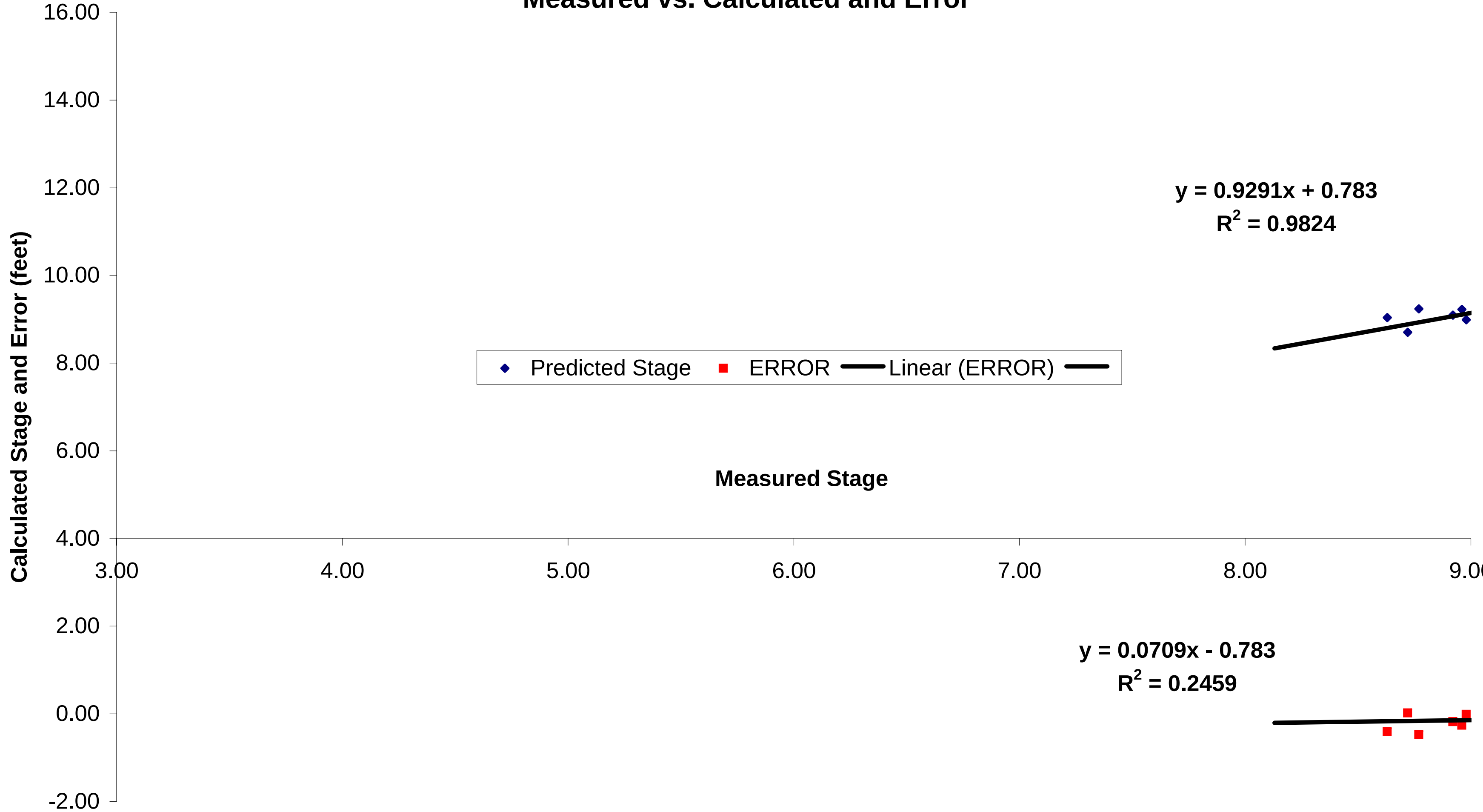


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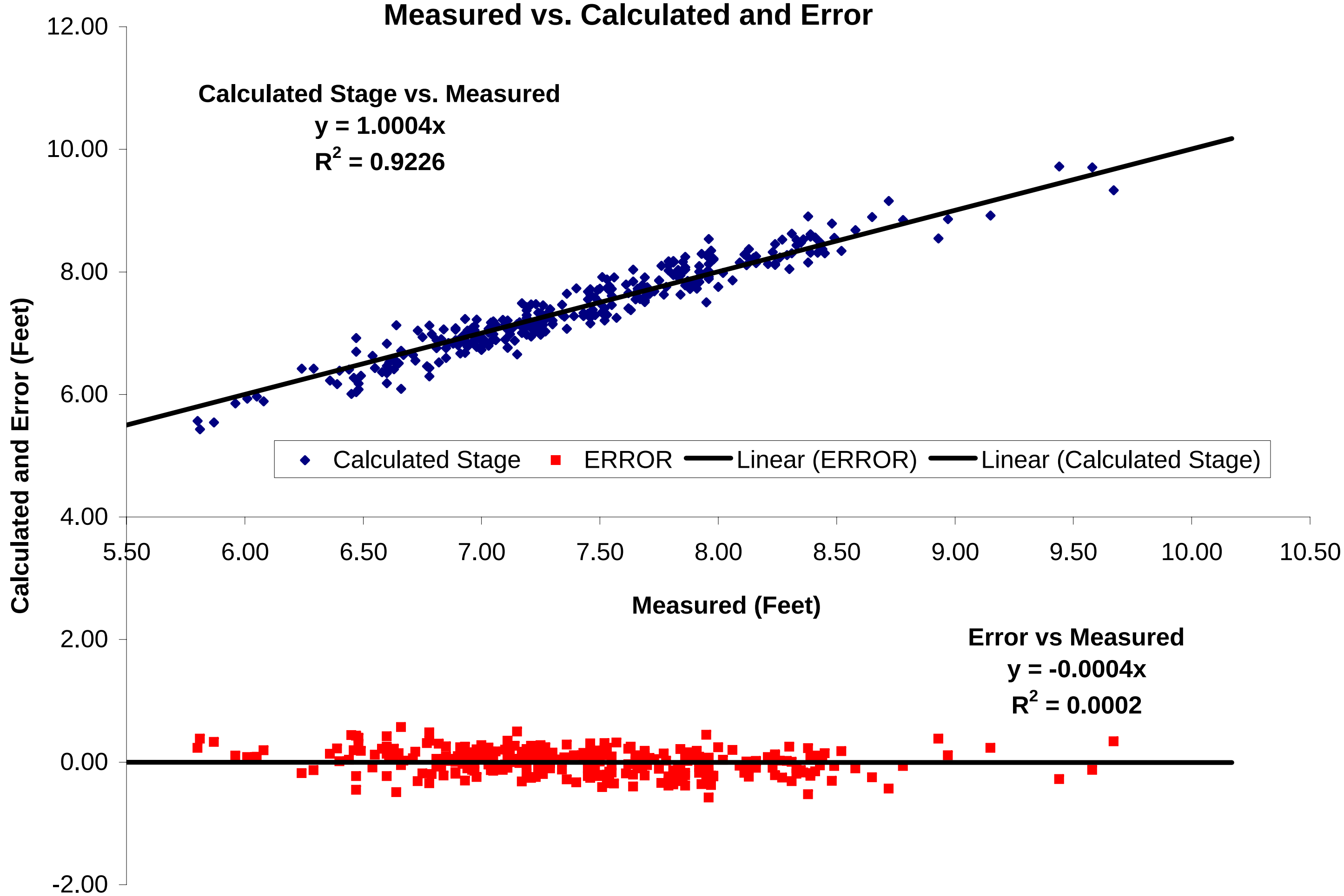
Figure A-21
VENICE ISLAND (VNI)
Measured vs. Calculated and Error



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Appendix B
DRMS Steering Committee/Agency Comments on Draft Flood Hazard Technical Memorandum
and
CALFED Science Program Independent Review Panel Comments on Draft Risk Analysis Report That Apply to Flood Hazard Technical Memorandum

DRMS Steering Committee/Agency Comments on Draft Flood Hazard Technical Memorandum

Delta Risk Management Strategy (DRMS) Phase 1
Response to Comments: Flood Hazard Technical Memorandum

Comments	Responses
Reviewer: Jensen and Burnham, U.S. Army Corps of Engineers, General Comments	
1. Climate change assumptions and procedures used are not clearly stated.	An unnumbered table summarizing climate change assumptions has been added to Section 6.1 of the Flood Hazard Technical Memorandum (TM). More detail is presented in the Climate Change TM.
2. The assumptions made and constraints used in the Flood Hazard technical memorandum limit its utility for more detailed studies	The method was not intended for more detailed studies but was designed for use in the Risk Analysis Report, where thousands of different simulations were conducted. Thus, the method needed to be simple and easily implementable.
3. The daily time interval used is too long to capture the peak flows, tidal effects, timing effects, outflows from the Delta, etc.	The intention of the analysis was not to capture short-term or transient effects. The intention was to provide a reasonable estimate of the peak stage in the Delta for each of the scenarios simulated in the Risk Analysis Report. Hourly stage and tidal data were used in the analysis.
4. The presented procedures do not take into account reservoir operations, by-passes/weirs and diversion operations, other non-controlled diversions, pumping operations, levee failures, and with-project base and future conditions that effect flows throughout the system.	The method was meant to be simple enough to be implementable in real time for thousands of potential simulations. An analysis of the stage data collected in the Delta indicated that the stage could be estimated with reasonable accuracy for purposes of the Risk Analysis Report. The analysis incorporate Yolo Bypass diversions. Operation of Delta Cross Channel is, in general, constant during the wet season.
5. The procedures do not provide adequate hydrographs required for unsteady and multidimensional flow analyses and interior flood analyses with respect to the Delta.	The analysis in the Flood Hazard TM was not intended for transient or multidimensional analysis. See the Water Analysis Module (WAM) TM for details on the modeling.
6. The results presented are not accurate enough for sizing and design of Corps levees or for FEMA levee certification analysis.	The flood hazard modeling was not intended for design purposes; it was only designed to provide input to the Risk Analysis. FEMA certification requires protection against a specific event at a specific location, not a specific inflow into the Delta.
7. While the procedures applied for estimating flow-frequency curves	The Flood Hazard TM has been updated to provide a more accurate description of the

Comments	Responses
associated with the four climate change scenarios are logical, the assumptions and data used do not enable consideration of different reservoir and system operations strategies to be studied. These strategies will need to reflect changes in the snow pack and runoff predicted by the climate change models (see Climate Change technical memorandum). The assumption that the 23 large watersheds' 100-year (or other) frequency flows can be added together to produce the 100-year Delta flow is invalid. Furthermore, there is no documentation of the assumptions, procedures, and results of the climate change analyses.	procedure followed. Although future reservoir operations may be different than they are today, the purpose of the flood hazard analysis was not to analyze reservoir operations, but to estimate how the flood frequency curve may change in the future. It would be speculative to try and operate the reservoirs under future, uncertain conditions and would be unlikely to provide a better, more certain estimate of the future flood frequency needed for the Risk Analysis inputs.
Jensen and Burnham, Specific Comments	
1. <u>Section 1.1, page 5</u>. More discussion is needed here on the specific results of the technical memorandum, i.e., what information is being produced as an input for the Risk Analysis model.	Section 1.2 was expanded to better explain model output.
2. <u>Section 2.</u> This section states that a daily time interval is adopted for the analyses. The Corps presently uses a one hour time interval to model its reservoir systems for floods. The technical memorandum report must demonstrate that a daily time interval is appropriate for flood estimates throughout the Delta. One way would be to show the differences between daily and shorter time intervals in peak stages at various gages throughout the Delta. The comparisons should be made for the range of annual peak events of record for all pertinent recording stage gages in the Delta.	The hydrologic analysis does not have a time component. The hydrologic analysis develops hydrologic events and probabilities to use in the Risk Analysis. In developing the events and their associated probabilities, daily flow rates were used but hourly measured stage data were used to develop inflow-stage relationships. The methodology provides accurate estimates of water surface elevations considering the wide range of variables that must be considered in the Risk Analysis.
3. <u>Section 2.1, page 6</u>. The text states that Figure 2-1 shows where water surface elevations were measured. The only gage locations shown on Figure 2-1 are the flow measurement locations.	A new Section 2.1 has been added. Figure 2-1 is presented in Section 2.2 and references only the flow measuring stations; Figure 5-2 shows the stage-measuring stations. The text was corrected.

Delta Risk Management Strategy (DRMS) Phase 1
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Comments	Responses
4. Section 2.2, page 6, also last paragraph page 10. The use of the PMF obtained from USBR would seem appropriate. Where are their values? The use of the data set in Table 2.1 with mostly very small drainage areas (DAs) and the application of a simple regression equation to estimate PMF peak flows for the significantly larger basins with totally different characteristics flowing into the Delta are inappropriate. The arbitrary assignment of a 1 in a million probability to the PMF is also inappropriate. Therefore, it is not appropriate to use the PMF as an upper bound on the frequency curve. The Corps does not assign or estimate probabilities associated with the PMF. One could determine where the PMF falls on an adopted frequency curve, but its frequency will vary with location.	The PMF data used in the analysis are provided in Table 2-1. The PMF estimates are for watersheds located throughout the U.S., including three in California. It is true that the PMF does not have a probability associated with it. However, the purpose of using the PMF was not to associate a probability with the PMF but to bound the flow associated with extremely rare inflow events, should that be needed for the Risk Analysis. Generating extremely rare flows from a frequency distribution can result in flows that are impossible; it is therefore necessary to bound the upper limit on flows from the probability distribution. We recognize that this approach is simplistic, but the results are not sensitive to the probability assigned to the PMF. It should be noted that the USBR PMF estimates include 61 floods located throughout the United States, including three floods located in Northern and Southern California.
5. Section 2.3, page 7. The discussion on selection of the period of record used is good. The 13 years of pre-Oroville Dam record is probably meaningless. Regardless, the process used to select the record for analysis seems reasonable.	Noted.
6. Last paragraph, page 7, and second paragraph, page 8. It is likely that the adoption of a daily time step significantly dampens the true impact of reservoir operations on peak flood flows and stages.	Several inflow hydrographs were reviewed and showed that the inflow peaks were very long (several days) and flat (little variation in total inflow). Also, the reservoirs are located far from the Delta, so interday or even daily changes in reservoir operations are unlikely to affect the flows into the Delta, as the changes will be smoothed out during the travel time to the Delta.
7. Second paragraph, page 8. The technical memorandum states that reservoir and diversion operations are not considered in the analyses. How then will base and future conditions alternative reservoir systems operation strategies, required for analyses	It is not clear that current reservoir operations have a significant impact on flood inflows into the Delta. Therefore, it is unclear that future operation of the reservoirs will have a significant impact on reducing flood damages. Also, the intention of the Flood Hazard TM

Comments	Responses
of climate change (significant snow-pack reduction and more rainfall) and Delta levee modifications, be consistently evaluated against the presented existing conditions?	was not to analyze reservoir operations. See the Water Analysis Module (WAM) TM for analysis of reservoir operations.
8. Last paragraph, page 8. If only 18 events are higher than 200,000 cfs during the entire 50-year period of record, are only 18 data points used in the frequency analysis? It appears in Section 3 that 50 points were used: Why then are we discussing only looking at flows over 200,000 cfs in this section? Needs clarification.	Fifty (50) annual peaks were used in the frequency analysis. The 200,000 cfs lower limit has been removed, and the analysis now includes all annual flows.
9. Section 3.1, page 9. There are inherent errors when using curve fitting techniques for flow frequency analysis. There should be some discussion on the estimates of this error and what it might mean in the analysis. Gordan et al. (1992) shows a 25% error if only 48 years of record are used to estimate a 100-year event.	We are not sure what the commenter means by "error," but we agree that there is a large uncertainty in estimating rare events from small data sets (such as the 100-year event with 48 years of record). Also, uncertainty exists in the choice of frequency distribution to use in estimating the frequency of a particular flood event. Section 3.3 discusses the uncertainty analysis used in the flood frequency analysis. For each flood event (e.g., 100-year event) the 5%, 20%, 50%, 80%, and 95% confidence bounds were also calculated. The Risk Analysis Report uses all the confidence bounds in its calculations instead of a single estimate for each flood event.
10. Last sentence, page 10. While the Delta inflow may not be sensitive to the PMF frequency, the integration of the damage-frequency curves for without and with project conditions analyses can be very sensitive to the frequency assignments to all flow values including those that are extreme.	It was anticipated that the Risk Analysis Report would not need to simulate results for extremely large events (e.g., > a 500-year event), as most levees would fail before such a large event. Once a large number of levees have failed, simulating larger events does not significantly increase the level of damage. We were not sure where this level would occur, but it was assumed to be much smaller than the PMF or 1 in a million event.

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11. Section 3.3, page 11. More discussion is needed to explain the arbitrary cutoff of the PMF at 3,000,000 cfs.	The number of flow bins was expanded to cover a wider range of probabilities. However, as listed in Table 3-5, the upper limit is still at 3,000,000 cfs. It was assumed that it is highly unlikely that a greater flow than this would ever occur in the Delta and furthermore that even if such as flow were to occur, all the levees would have failed long before 3,000,000 cfs reached the Delta. So, it was decided not to provide probabilities for larger inflows.
12. Section 3.4, page 11. Need more discussion about how the results are used for input into the Risk Analysis.	Text added to Section 3.4 to clarify.
13. Section 4. The procedures presented are interesting and logical for a basic level of analysis developed with limited resources for a very complex study.	Noted.
14. Section 4.2, page 13, Eqn 4-3. Would like to see the reference cited for this equation.	Neter, John, and William Wasserman, *Applied Linear Statistical Models* (Richard D. Irwin, Inc., 1974).
15. Last paragraph of Section 4.2, page 14. Need more discussion and backup calculations to describe why the regressions are adversely affected by the San Joaquin and Consumnes rivers.	The text was changed to better reflect why the flows were analyzed in the prescribed order.
16. Section 4.3, second paragraph, page 14. Describe the curve on Figure 4-1 that represents the fraction of inflow. How is this curve used in the calculations?	The curve for the fraction of inflow was not used in the calculations; rather, it was provided because it is an intermediate result used to calculate flow in the tributary.
17. Sections 5.1 through 5.4. Procedures and assumptions made for data adjustments are valid.	Noted.
18. Section 5.5.1, page 19. Second paragraph makes an excellent point about bias and removal of the low flow data sets from the analysis methods. Why is 57,000 cfs used as the cutoff for high flow here, whereas in Section 2, the cutoff for high flows was 200,000 cfs?	The limited stage data required lowering the minimum value of “high inflows.” If 200,000 cfs were to be used, we would not have enough data points for a regression analysis at some measuring stations. We used 57,000 cfs to include the highest flows in the available data for the San Joaquin River.

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19. Section 5.5.2, page 19. Equations 5-1 and 5-2 do not consider outflows to the SF Bay, pumping, diversions, or non-federal levee failures (storage) that will occur during modest flooding. Why are these factors not considered? How significant are they to estimating an accurate water surface elevation?	It is true that factors other than inflows could affect the water surface elevations at a given station in the Delta. This was noticed to be especially true for stations near the Federal and State Project pumps. Appendix A provides a comparison between measured and predicted stages, and the accuracy was considered adequate for the Risk Analysis. The stage elevation at the Golden Gate was considered to define the tail water condition. Outflows were considered a function of the inflows and stage elevation at the Golden Gate. Pumping is assumed to be steady state and not variable and certainly makes a difference. This difference is already accounted for in the historical stage elevations. We looked at levee failures and found them to be fairly frequent. We considered eliminating data from events that had levee failure. The records we have on the exact timing of levee failures are vague, and the timing of their eventual repair was not readily available. As nearly every major storm broke a levee some where, if we were to eliminate these storms there would be little data left to examine. Also, for major events the inflow data indicate that the volume of inflow is significantly greater than island storage and once the island is filled, it would have less impact on water levels in the Delta, though more inflow may be directed to the flooded island due to the added tidal prism.
20. Section 5.5.2, page 19, first paragraph. The following relationship is used: the hydraulic head is proportional to discharge to the 0.67 power. The use of this relationship as the exponents in the equations seems arbitrary. However, given the type of analysis, it is a very good	See first paragraph after Equation 5-2.

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assumption. A reference should be cited.	
21. Section 5.6, page 20. Much of the validity of the procedures hinges on the results described in this section. The comparison of stages at the gages presented in Figure 5-4 and Appendix A is limited to a selected number of events. Review of comparisons shows that some predictions are very good and others are off as much as 1-2 feet. Tables for each stage gage, non-recording and recording, need to be developed to show all the annual peak events, the predicted peak mean daily stage, and the recorded peak mean daily stage. For recording stage gages, all other available shorter time period data (such as 12-hr, 6-hr, 1-hr) should be shown as well. Differences in feet between the recorded and predicted stage values should also be provided in the tables.	A table was added to Appendix A comparing the observed and predicted peak stage at each station with at least 4 years of data. The observed stages are from hourly data. Results are not shown for different time periods, as information on different time periods is not needed for the Risk Analysis Report. The Risk Analysis only needs a single value for each station for each scenario.
22. Section 5.7, page 20. Given the high levels of flow during floods, failures of numerous non-federal levees, complex and dynamic flow patterns, potential of high tides, etc., how accurate is the interpolation? Can an assessment of the accuracy be made? An example location and calculation would be helpful. An HEC-RAS model of the North Delta was completed by UC Davis within the last couple of years. A comparison of stages developed from this Flood Hazard technical memorandum's regression model and from the HEC-RAS model at several locations within the North Delta (using same inflow values) would give more confidence in the accuracy of the regression model.	The commenter provides an idea worth pursuing. If more time were to become available, then an analysis such as the one the commenter has proposed could be explored.
23. Section 5.8, page 20. The discussion of assumptions and limitations is good, although more could be added.	Noted.

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24. Section 6.1, page 21. The technical memorandum on Climate Change does not go into sufficient detail about the modeling process of the four scenarios or the assumptions made to feel comfortable with the results. Significantly more background information is needed on assumptions, analytical procedures, and results. What are the 23 streams, how were the synthetic records generated, etc. Finally, as precipitation is critical to the results, and climate change models are known to have problems in analyzing it, how is precipitation addressed in the climate models?	Addressed in the Climate Change TM.
25. Section 6.1, page 21, third paragraph. The assumption of the 100-year runoff event for each of the 23 watersheds above the reservoirs being added together to produce a total 100-year inflow frequency in itself would essentially discredit the climate change analysis. The results for these very large watersheds would produce a far rarer frequency event for the Delta inflow. As presented, the use of the 7-day mean daily flows added together would negate some of this problem but not address the reservoir system operation factor. How could this be improved?	The text was misleading in how the future conditions were calculated. The text has been updated to better describe how the future conditions were estimated. The analysis determined the 1% chance of the sum of the 23 stream flows, not the 1% chance of each of the 23 stream flows summed.
26. Sections 6.2 through 6.5. These sections describing the general procedures used to depict the frequency curves for the four climate change scenarios seem logical and valid. The assumptions associated with the 23 watersheds' synthetic record generation and assumed Delta total inflow frequency still leave major questions about the validity of the climate change analyses results.	Addressed by the climate change group.

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27. Section 6.2.1, page 22. Briefly include a discussion of the four climate change scenarios and include a summary in the table instead of a meaningless number	An unnumbered table was added to the text to provide an explanation of the numbering system used for climate change.
28. Section 6.2.4, page 23, first sentence. This assumption is simply not valid and discredits the entire results of the global warming analyses for the four alternatives. The frequency analysis plotting positions would be much different. How to resolve this issue is paramount to the climate change part of the technical memorandum. Also, comparing the synthetically generated flow data to the observed flow data records is not credible without a detailed explanation of how the records are generated.	The method used in the analysis was not clear in the text; the text has been corrected.
29. Section 6.5, page 25, Equation 6-1. Using Manning's equation to approximate the stages due to rises in the ocean seems very simplistic, given the many factors involved and complexities of the hydrodynamics of flows in the Delta.	The method is simple but provides a measure of the how far sea level rise may extend inland during a storm event. Although simple, the method was considered adequate for the level of detail needed by the Risk Analysis Report.
30. Page 26. The technical memorandum text ends abruptly. Add a conclusion or summary section.	A summary section was added (Section 7).

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Comments	Responses
Reviewer: Keer, U.S. Army Corps of Engineers	
1. Analysis needs to research approaches taken by other studies; listing what the modeling needs are and explaining how what's already been done fits within the confines of the existing study. The documentation provides no indication that any research of existing studies was done and provides explanation of what was found and how that information was incorporated into the DRMS analysis or why it was excluded.	The purpose of the Flood Hazard TM was to develop inputs for the Risk Analysis Report. The inputs required were specific and needed to be stated in a probabilistic framework. Other studies were reviewed, such as the USACE Sacramento-San Joaquin Delta Special Study (Hydrology) 1992 and the sections of the Sacramento and San Joaquin River Basins Comprehensive Study (2002) and FEMA FIS. However, these studies were conducted for different purposes, and the results were not found to be relevant to the Risk Analysis.
2. Language states that "other team members will use the results of these studies to evaluate risks of potential damages in the Delta". The document needs further develop the application of this process within the text; there's no mention of how it's intended to be applied beyond the Phase I and Phase II stages of the DRMS analysis. Is it expected to support any type of alternatives analysis? Are there specific agencies that the current DRMS analytical team expects will be utilizing the information they've developed? If so, what are those agencies and how does the current Phase I and II analysis fit into the scope of their analysis? How does this analysis fit within their minimum acceptable criteria?	The purpose of the Flood Hazard analysis was to develop inputs for use in the Risk Analysis Report for Phase I of DRMS. If similar information is needed for Phase II, the Phase I information will be modified appropriately. The information developed as inputs to the Risk Analysis Report was not intended for or designed for use for other purposes or by other agencies outside of DWR.
3. Might the general conversion of all station datum to NAVD 88 be eliminating subtle differences in stages between gages – the stages at each of the gages are averaged and that average compared to another average.	To use the stage data for a Delta-wide analysis, it was necessary that all the data be on the same datum. It is possible that the errors in converting stages from one datum to another could be on the order of "subtle" differences between datums, but without converting the stages to the same datum the "subtle" differences cannot be identified.

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4. Only two flow seasons are being considered; high - 16 December through 15 April, and low - 16 April through 15 December. This delineation simplifies the analysis, but might provide misleading results if this is the same delineation used in the frequency analysis (i.e., separating dependent and independent data). Annual peaks represented for water years 1971, ‘76, ‘85, and 2005 are classified within the “Low Runoff Season” the rest are in the “High Runoff Season”. Frequency analysis doesn’t separate flow components based on their source. What are the implications of relying on statistics developed from mixed populations when the recommended application of the Log Pearson III distribution by the IACWD is applied independent data?	It is unclear what the commenter is asking. Each of the three frequency distributions was analyzed independently. The annual frequency distribution was based on the annual peak for each year, the high season was based on the annual peak during the high season, and the low season was based on the annual peak during the low season.
5. USBR PMF data is used to determine the upper limit of inflow into the Delta. The PMF data cited was developed for other states across the continent – applying inferences from this data specifically to the Delta is inappropriate. The estimate is based on an equation defining the trend of PMF cfs/mi2 versus watershed area mi2; based on PMF CSM values developed by the USBR for different drainage basins throughout the country. CSM values can vary widely-just in comparing basin productivity between the Sacramento Basin and the San Joaquin Basin - one can be twice that of the other. Plotted against the CSM values, the CSM value represented herein lay on the extreme lower end of the trend…possibly as an outlier. PMF discharge values are typically used for spillway design…what is their application in this analysis; economics…they’re not needed-all this study should be worried about is maybe a 1/500 stage.	The PMF analyses were used to give an approximate upper limit on the flow that could be generated from the flood frequency distribution. It is not anticipated that any flows larger than about a 500- to 1,000-year event would be needed.

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6. The document doesn't support it's assumption that "hydrologic risk of damages in the Delta is not expected during inflow events less than 200,000 cfs" (page 8, paragraph 3). The Middle River reach of the Jones Tract levee failure occurred 3 June; according to Figure 2-3, at a peak Delta inflow less than 150,000 cfs.	The lower limit of 200,000 cfs was removed. The analysis now includes flows from 0 to 3,000,000 cfs.
7. Investigation assumes New Melones and Oroville dams have no significant impact on Delta inflows. This assumption will have a significant impact on the analysis – suggest either rethinking this approach or quantifying the impacts. If "the average number of days per year with high Delta inflows from SJR is greater during current conditions [record reflected with regulation]"…then NML is impacting Delta inflows (more comments below in Section 2.3 paragraph 4). This assumption appears to be in conflict with a statement made in Section 6.1 that "…estimated inflows into the Delta in some streams during some storm events may be significantly attenuated by reservoirs…".	The discussion in Section 2 on the effect of reservoirs on flood flows into the Delta was used to decide if all 50 years of available data could be used in the analysis or if only data collected after construction of New Melones could be used. Before the analysis it was hypothesized that the reservoirs would decrease flood flows into the Delta and therefore there would be a noticeable decrease in the size of inflows into the Delta after construction of the reservoirs. As described in the Section 2, that did not seem to be the case, so it was decided that all 50 years of data could be used in generating the frequency distribution of flows into the Delta.
8. The results of the inflow patterns methodology (Sacramento River vs. Yolo Bypass) Section 4.3 assume that the fractional contribution of the Sacramento River to total delta inflow (TDI) is never less or more than between 85% and 92%. This is clear within Figure 4-2 (Flow in Sacramento River Plus Yolo Bypass versus Total Delta Inflow); is it realistic that this relationship always fit within these bounds?	It was not assumed a priori that the fractional contribution of the Sacramento River to TDI was between 85% and 92%. The only assumption was that the contribution was restricted to between 0 and 100% (due to the use of the logistic regression). The actual limits that are produced are a function of the regression coefficients and the standard error of the regression. The median estimate of the fraction may be between about 85% and 92% for flows from about 200,000 to 2,000,000, but including the variability about the median results in estimates that could vary from 60% to 99%.

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9. "Water levels, or stages, at the selected gauging stations were then used to interpolate stages at intermediate locations in the Delta" (Section 5.1, page 15). The statement assumes that there are no structures in-between the two points that would create any hydraulic inconsistencies, or levee bank elevations lower than the proposed water surface that might create an out-of-bank flow…again providing a different water surface elevation. This assumption appears to limit the ability of the DRMS analysis to be directly applied in any type of alternatives analysis.	Stages were estimated as inputs to the Risk Analysis Report. Simple methods were needed to allow for the large number of scenarios anticipated to be calculated in the Risk Analysis Report. The estimates predict the maximum river stage assuming infinitely high levees. These stages are then compared to actual levee crest elevations to evaluate the likelihood of levee failure. In Phase II the method will be modified if necessary depending on the alternatives that need to be analyzed.
10. The analysis states "That failures in the levee system for any given flow conditions are minimal and will not significantly reduce the stage elevations along the channels" (Section 5.8, page 21, 1st paragraph) This is a great assumption …how is it expected that we're to utilize this study to formulate hydraulic alternatives when this analysis itself isn't able to provide hydraulic insight. What is the elevation at which overtopping of the levees occurs?	The method was designed to provide inputs to the Risk Analysis Report. It was not designed for an alternatives study. It will be modified as necessary if alternatives are identified for the Risk Analysis that need stage data. See the Water Analysis Module (WAM) TM for a description of the detailed hydraulic analysis.
11. The assumption that "a runoff event of a given return frequency that occurs in the watershed will produce a Delta inflow of the same return frequency" implies that regulation has no effect on Delta inflows. Data development states the conclusion "…that construction of reservoirs and other developments in the watersheds tributary to the Delta [does not appear to] have a significant impact on annual peak daily Delta flood inflow characteristics…"…only applies to flood events and not non-flood flows". In conflict, with the above statement, Page 4, paragraph 4 states that "…hydrologic characteristics in the Delta during different inflow seasons were considered in the	The text was modified to read, *The future change in frequency of a watershed event with a given current return frequency will produce the same future change in frequency for the Delta inflow of the same current return frequency.* It is not clear from the data that regulation has had an impact on flood flows into the Delta. This was the basis for using 50 years of data rather than only the data since construction of the last reservoir.

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studies."	
12. The last paragraph of Section 3.1 provides a justification for the DRMS flood frequency analysis by comparison with the Comprehensive Study results. This comparison is misleading unless the reader understands the assumptions of the Comprehensive Studies Rain flood Frequency Analysis. The unimpaired mainstem discharges (259,295 cfs) were, at latitude, mass routings of discharge coming off the tributaries; the HEC-5 routings of those unimpaired discharges (98,863 cfs) assumed an infinite channel (i.e., zero losses); the hydraulic routings of regulated discharge (77,300 cfs combined) through the lower basin floodplain to Vernalis made assumptions regarding upstream levee breaches. This information is quite different from any gauged data used in the DRMS analysis, which may or may not reflect over/out of bank flow – how can a comparison be made with such widely different development approaches. The last paragraph of Section 3.1 states the 1-day, 0.01 probability discharge at Verona developed by the Comprehensive Study as 60,000 cfs…it's uncertain where this value was obtained.	The comparison to the Comprehensive Study was included in response to a comment received on an earlier draft. The comparison has been removed.
13. Section 2.3 paragraph 3; how were impacts of watershed changes on Delta inflows considered?	Watershed changes are known to have occurred during the period of Delta inflow record. Analyses were made to determine if these changes resulted in any significant and identifiable changes in Delta inflows.
14. Section 2.3 paragraph 4; I believe the assumption that ORO and NML have no impact on Delta inflows is incorrect. The comparison made is over simplified and misleading. Simple comparisons between regulated and unregulated frequency curves contradict this assumption.	The analysis is simple yet it does indicate that the reservoirs have not had the effect on Delta inflows that might be expected. The purpose of the analysis is not to determine the level of impact of reservoir operations on flows in the tributaries to the Delta but determine if the use of 50 years of data that encompasses an era of dam building is reasonable. The analysis indicates that the use of the 50-year

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	data record is reasonable for the purpose of the Risk Analysis.
15. Section 2.3 paragraph 5; the suggestion that "fewer peak daily inflows would be expected after the addition of reservoirs in the watersheds if the reservoirs were reducing flood flows" cannot be directly supported without a statistical comparison of reservoir inflows, storm patterns, and ungaged contributions.	Disagree. It is not unreasonable to anticipate that the construction of reservoirs will reduce peak flood flows downstream of the reservoirs. That is often why they are built.
16. Section 3.1 paragraph 1; is the reference to table 3-1 summarizing "annual peak" total delta inflows or the annual "daily maximum"? This ambiguity also needs to be clarified in Table 3-1.	The table summarizes the annual maximum daily average flow.
17. Section 3.1 paragraph 3; figures 3-1, -2, -3, and -4 need to display the Annual Probability of Exceedence on a probability axis; if they are, then the axis need better labeling and identification. These plots need to present for clarity the moments used in plotting these points.	The probabilities are plotted on a log axis and are labeled correctly. It is unclear what the commenter is requesting.
18. Section 3.1 paragraph 4; the first sentence states that the flood frequency analysis developed as part of the Flood Hazard Analysis has a slightly different definition than the definition typically used…how is this?	The flood frequency developed in Section 3 is for total Delta inflow, which comes from several sources. The frequency does not apply to any particular source or a discharge at a specific location. Therefore, it is possible that an estimate of the 100-year event from the frequency distribution will not result in a 100-year event on any tributary or at any location in the Delta.
19. Section 3.2 paragraph 4; there's a questionable difference between the computed and weighted skews values presented in table 3-3; maybe a typo?	Table 3-3 has been corrected.
20. Section 3.3; need further clarification on this section. It's not clear.	Some clarifications have been added to this section.
21. Section 4.2; difficult understanding the methodology; an example should be worked out.	Scheduling does not allow inclusion of an example for the Phase 1 submittal. An example will be provided during Phase 2.

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22. Section 4.3 Figure 4-2; the graphical analysis terminates at a total delta inflow of 800,000 cfs.; what about a TDI of 3,000,000 cfs? The regression oversimplifies the hydrologic contributions of the Sacramento River/Yolo Bypass; there appears to be almost 30% variability in the Sacramento River/Yolo bypass contributions to total delta inflows. There is no fit here…is the assumption that whenever the total delta inflow is 200,000 cfs that the Sacramento River is contributing 85% of that flow…<u>always</u>?	An inflow of 800,000 cfs covers the range of measured data. It is unclear how the regression in Figure 4-2 oversimplifies the hydrologic contributions of the Sacramento River/Yolo Bypass. It just compares the total flow in the Sacramento River/Yolo Bypass to the flow in the Yolo Bypass. The 30% variability in the Sac/Yolo contribution is what the data show. We disagree that there is no fit here. The fit is adequate for the Risk Analysis. The fit provides an estimate of the mean fraction of the flow. The uncertainty or variability analysis is used to capture the variability (e.g., the 30% variability identified by the commenter).
23. Section 4.3, page 12, paragraph 1; paragraph states that a relationship is presented in Figure 4-3, but doesn't clarify what conclusions are drawn or utilized from that relationship.	The relationship was developed as input to the Risk Analysis Report; no specific conclusions were developed.
24. Section 4.3 paragraph 2; disagree that the regression provides a visual good fit; it under predicts the main body of data because of all the low data values in that data set.	The correlation coefficients have been added to the text to better define the fit.
25. Section 4.3; references to the regressions "visually…appearing to fit the data well" are not reliable. Why are the only coefficients of correlation, provided are in Figure 4-3?	The correlation coefficients have been added to the text to better define the fit.
26. Section 5.2.1, page 16; language in the text states that the "Tide levels at the Golden Gate station are <u>relatively</u> independent of flows into the Delta…" at what event will Golden Gate tidal stages be dependent on Delta inflows?	For extremely large Delta outflows, there could be some effect on tides. This is an event that we have not yet seen.

Comments	Responses
27. Section 5.3; it would be beneficial to see complete data sets highlighting adjusted data points; coded with why they were adjusted. Were there any critical data points missing from the data sets (i.e., '97 peak at Vernalis…account only for in-channel flows, there were out-of-bank contributions; daily maxima omitted because of invalid recording intervals or incomplete daily records)? How many incomplete daily records were omitted? What were the criteria for deleting records that presented constant values of stage for extended periods of time?	With additional time and effort, a list of data point adjustments and the reason for adjustment could be provided. Some data were not included, as there is not a consistent range of data available across all stations. In some cases high stages knocked out station reading equipment so that there are gaps in the data.
28. Section 5.4, paragraph 2 and Table 5-1; what water years were chosen to compute the 28-day august average stage and what were the decisions made about the number of tide cycles used in the calculation?	Generally the most recent available years were used (2005–2002). Some earlier years were also used as a check on data shifts.
29. Section 5.4, paragraph 4 and Table 5-1; table 5-1 presents the "delta stations used to develop the approximate datum adjustments for inflow…the assumption here is that there were a slew of other gages (mentioned in paragraph 1) that don't have a know datum; where are these gages and their associated data	There are over 50 stations in the Delta but most have a very limited period of record (~1 year). The records were further limited to flows greater than the minimum flow considered, thereby reducing the number of data points to less than needed for the statistical analyses. We approached the datum at each station skeptically. The datum adjustments shown on the CDEC station metadata web pages are sometimes contradictory. Also, the data shifts at BEN, BDL, ROR and others kept us guessing what the correct datum was.
30. Section 5.4, paragraph 5 and Tables 5-1 and 5-2; what relevance is the hydraulic gradient between each stations and Mallard Island (MAL)?	The hydraulic gradient was used as a reasonableness check on the datum for some stations. The gradient was not used as a method to determine the datums. The hydraulic gradient during the minimum August flows should be very, very mild.
31. Section 5.4, paragraph 6 and Table 5-2; there's no explanation why the adjustments for SSS, FPT, and MAL are not the same as those provided in Table 5-1.	The second column from the right for each table (Table 5-2 and 5-3 in the revised TM) matches. This column represents the head at each station.

Comments	Responses
	Each of the stations mentioned was adjusted from NGVD to NAVD, whereas the other stations listed were not.
32. Section 5.5.1, paragraph 2; the inflow data sets were reduced to only include high inflow events, but only TDI magnitudes > 57,000 cfs are included in the analysis? What happened to the minimum TDI of 200,000 cfs?	There were not enough data points with flow greater than 200,000 cfs for some stations, so the cutoff was reduced to increase the number of data points; 57,000 cfs also includes the highest flows on the San Joaquin, as 200,000 cfs would not.
33. Section 5.5.2, last paragraph, Table 5-3; if I'm understanding the analysis and interpreting the table correctly, values of 0.00000 are indicating that particular tributary does not have a stage?	A coefficient of 0.0000 indicates that that tributary did not contribute to the stage for that particular station.
34. Section 5.6, last paragraph and Figure 5-5; not quite certain how Figure 5-5 verifies the equations. Is the idea that stages should generally decrease towards the Mallard Island gage (MAL)? Does only three points verify this assumption? Has there been any mention or analysis of having a variable downstream boundary condition…higher peak tidal stages with higher event inflows?	Yes, generally stage decreases toward Mallard for higher flows. Three to five points are shown, as that was what was available. The downstream boundary conditions are considered to be the maximum daily tide at the Golden Gate. Alone it does not verify the equation; it only shows that the equation meets an expected behavior. The figure was removed.
35. Section 5.7; not quite certain how Figure 5-5 verifies the equations. Is the idea that stages should generally decrease towards the Mallard Island gage (MAL)? Does only three points verify this assumption? Has there been any mention or analysis of having a variable downstream boundary condition…higher peak tidal stages with higher event inflows?	See response to comment 34.
36. Section 5.7; I believe this assumes there are no structures between the gages that are being interpolated in-between.	Yes. The Delta Cross Channel and Sacramento Weir can provide inconsistent results if they are not operated consistently. Additional refinement may be possible if the operational records for events are available. Larger events probably exceed the operational range of these two structures. The Delta Cross Channel is generally closed during the wet season.

Comments	Responses
37. Section 6.1, first paragraph; aside from incorporating the effects of climate change into the hydrology for this analysis…why did the DRMS climate change tasks group develop their own synthetic estimates of runoff? What was the point of the first four section of this report?	The first four sections of the TM were completed to provide estimates of the probabilities of inflow amounts, patterns, and tides for existing conditions. These, in turn, were used to calculate the probabilities of water surface elevations and various locations in the Delta. The probability of a set of concurrent water surface elevations throughout the Delta cannot be calculated directly from the measured water surface elevations. The synthetic estimates of runoff were only used to estimate how the flood frequency curve would change due to future climate change.
38. Section 6.1, fourth paragraph; I'm not aware that unimpaired flows are being utilized in this analysis; the influence of regulation is already reflected in the data sets and now a seven-day average is being used to further attenuate the Delta inflow…I believe this to be an underestimation of either the peak or the volume, whichever is being used (it's unclear).	Unimpaired flows were calculated for the watersheds. Changes in the frequency of these flows due to climate change were used to adjust the change in frequency in Delta inflow as determined from actual measurement of the current Delta inflow. The analysis in Section 6 is only to estimate the change in flood frequency due to climate change. The actual data used in the analysis are always based on the measured Delta inflow data.
39. Section 6.1, fifth paragraph; a seven day sum…wouldn't the annual maximum 7-day total over estimate the inflow? Was this to be a 7-day average, if so this would under estimate discharge?	The analysis in Section 6 is only to estimate the change in flood frequency due to climate change. Actual Delta inflow data were used in the analysis.
40. Section 6.2.1; the statement that "No hydrologic condition could be identified that would cause the skew coefficient to change with time" needs to be verified against the data sets that were developed within in the Climate Change TM. Skew will change as the basin response changes; as climate changes; LPIII methodology requires that the data be stationary; what were the assumptions that were put into developing the different data sets reflecting the four climate change conditions?	The climate change results did not indicate a rapid change in basin runoff characteristics, so stationarity could be assumed over a limited time span, 50 years in our analysis. Each dataset in the climate change result had a different skew. However, since results are sensitive to the skew it was decided to not change the skew between the 50-year data sets extracted from each of the four future climate change models.

Comments	Responses
41. Section 6.2.1; so the skew coefficients were developed from the 150 year records developed within the Climate Change TM…were the skews developed from the annual peaks as stated, or the annual daily maxima or 7-day average? This section need	The annual peaks of the 7-day 23-stream totals.
42. Section 6.2.2; so the skew coefficients were developed from the 150 year records developed within the Climate Change TM…and then applied to the 50-year subsets?	Yes.

Comments	Responses
Reviewer: Scott Stonestreet, U.S. Army Corps of Engineers	
1. The following comments apply primarily to the hydraulic aspects of the assessment, not so much to the hydrologic aspects.	Noted.
2. Given that this effort was limited to using data and engineering and scientific tools readily available, the general approach of using the vast amount of historic data from the various tide and/or stream gaging location makes a lot of sense. However, while developing regression equations for existing conditions may be OK for describing existing conditions, the approach may be weak when it comes to using the equations to predict future conditions for the with-project condition, especially when the with-project condition invalidates the assumptions required to make the regression analysis meaningful. Additionally, the resolution of the gaging data is thin (e.g., only a handful of stations are available compared to 1100 miles of delta levees) and may not lend itself to producing information detailed enough to differentiate one alternative from another.	Depending on the alternatives that are analyzed in Phase II, the method developed for Phase I would likely be modified.
3. Given that this effort was limited to using data and engineering and scientific tools readily available, the general approach of using the vast amount of historic data from the various tide and/or stream gaging location makes a lot of sense. However, while developing regression equations for existing conditions may be OK for describing existing conditions, the approach may be weak when it comes to using the equations to predict future conditions for the with-project condition, especially when the with-project condition invalidates the	See the Water Analysis Module (WAM) TM for a description of the detailed modeling that was conducted. The purpose of the Flood Hazard TM was to develop inputs to the Risk Analysis Report.

Comments	Responses
assumptions required to make the regression analysis meaningful. Additionally, the resolution of the gaging data is thin (e.g., only a handful of stations are available compared to 1100 miles of delta levees) and may not lend itself to producing information detailed enough to differentiate one alternative from another.	
4. Future efforts in the Delta study will inevitably require the construct and use of a sophisticated delta-wide hydraulic model to answer the what-if's associated with flood events in the Delta (i.e.,. given the limitations of the DSM2 model with regards to flood events a model such as HEC-RAS is required). The regression analysis would not produce sufficiently detailed or high enough resolution results on which important decisions will need to be based. Thus, the documentation should discuss the need for a delta-wide modeling effort, its usefulness and limitations and show the benefits of such modeling over the regression analysis.	See the Water Analysis Module (WAM) TM for description of the detailed modeling that was conducted. The purpose of the Flood Hazard TM was to develop inputs to the Risk Analysis Report.

Delta Risk Management Strategy (DRMS) Phase 1
Response to Comments: Flood Hazard Technical Memorandum

Comments	Responses
Reviewer: Mike Anderson, DWR	
1. This was a challenging document to read. It lacks a clear focus and order which makes extraction of useful information difficult. As such, here is my understanding of what was conveyed in the document. The authors use the parameter Total Delta Inflow (TDI) to assess flood risk/vulnerability in the Delta. According to the authors, a maximum daily TDI of 200,000 cfs is the threshold for considering risk of flood damage in the Delta. Using this threshold, the authors use the Log Pearson III distribution to examine flood frequency of TDI. Regression equations were developed to generate river flows associated with a given TDI. The authors note that different patterns can produce the 200,000 cfs threshold which impacts the regression equations.	The threshold on considering risk (200,000 cfs) was removed from the analysis. The rest of the paragraph is accurate.
2. A second analysis was performed looking at water surface elevations. Regression equations were developed to predict stages at gaging sites given the maximum daily tide and mean daily inflow. Once stages at the gaging sites were determined, channel water surface elevations were spatially interpolated. This information was used to determine a Delta water surface elevation corresponding to a 100-year event.	The method described in the paragraph is correct. The expected 100-year event water surface elevation was not calculated; nor was any other return period event for water surface elevation calculated. A relationship was developed that could be used in the Risk Analysis Report to calculate stage for any given inflow condition.
3. The chapter then changes gears and discusses levee failures. Historical events are analyzed to determine if the frequency of levee failures has increased. Levee failure modes during floods were then reviewed. Analyses with a computer model were then carried out to determine potential levee failure sites and conditions. The results of these simulations were used to extrapolate the probability of island levee	Noted. See revised Section 7 of Risk Analysis Report.

Comments	Responses
failure.	
4. The document would benefit from an introduction that states the goal or message of the document followed by a clear description of what material will be presented to achieve this goal or message. I am not sure the discussion of dam construction is worth including in the document. It is poorly written and it is not clear if the analysis is sound.	Noted. See revised Summary Report and revised Section 7 of Risk Analysis Report.

CALFED Science Program Independent Review Panel Comments on Draft Risk Analysis Report That Apply to Flood Hazard Technical Memorandum

Section 7 (Flood Risk Analysis)

General Comments:

This section has all the shortcomings of the previous sections in minimal citations, poor justifications of statements, attribution of sources for data, etc. These omissions and problems extend throughout the section. There are some other concerns related to technical issues. Also, there are very detailed comments from reviewers on the technical memoranda for this section (see those from the USACE by Keer, Jensen, and Burnham) that very precisely identify problems that still seem to remain in the DRMS *Phase I Report*. The statements below are reproduced from these reviews (Jensen and Burnham) and address some of the critical issues:

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1. The Draft *Flood Hazard Technical Memorandum* presents a means of:
   - Estimating the Delta total daily inflow for flood events and associated stages throughout the Delta.
   - Establishing existing or baseline frequency curves.
   - Adjusting those curves based on four climate change scenarios.

   The analyses are based on readily available data. To the extent that the analytical study constraints permit, the procedures adopted and applied are logical and accepted within the profession, with one exception: The climate change sections in which procedures used and assumptions made are not clearly presented in this Flood Hazard technical memorandum or in the Climate Change technical memorandum. Excluding the climate change analysis, the resulting procedures from the Flood Hazard technical memorandum can be used to conduct preliminary analyses in order to focus more detailed studies and identify reasonable alternatives.

An unnumbered table summarizing climate change assumptions has been added to Section 6.1 of the Flood Hazard Technical Memorandum (TM). More detail is presented in the Climate Change TM.

2. The assumptions made and constraints used in the *Flood Hazard Technical Memorandum* limit its utility for more detailed studies. The primary reasons are as follows:
   - The daily time interval used is too long to capture the peak flows, tidal effects, timing effects, outflows from the Delta, etc.

The method was not intended for more detailed studies, but was designed for use in the DRMS risk analysis, where thousands of different simulations were conducted. Thus, the method needed to be simple and easily implementable.

The intention of the analysis was not to capture short-term or transient effects. The intention was to provide a reasonable estimate of the peak stage in the Delta for each of the scenarios *simulated in the risk analysis. Hourly stage and tidal data were used in the analysis. (Section 2.4.1, pp. 7 – 8)*

- The presented procedures do not take into account reservoir operations; bypasses, weirs, and diversion operations; other non-controlled diversions; pumping operations; levee failures; and with-project base and future conditions that effect flows throughout the system.

The method was meant to be simple enough to be implementable in real time for thousands of potential simulations. An analysis of the stage data collected in the Delta indicate that stage could be estimated with reasonable accuracy for purposes of the risk analysis. The analysis incorporates Yolo Bypass diversions. Operation of Delta Cross Channel is, in general, constant during the wet season.

None of the upstream facilities is explicitly included. They are, however, implicitly included in our approach of using the historic Delta streams inflow. The contributions of all the upstream facilities are reflected in the downstream flows. We need to stress that an important aspect of selecting this approach is that we never planned to perform a comprehensive analysis of the storms-watersheds-reservoirs-stream channel dynamics-levees along the streams etc. comprehensively all the way into the Delta. This work would be out of the scope of this risk study, and would require, in our estimation, 10 years or more to complete. Currently the USACE is working on this project deterministically and for today's condition. Think about the additional efforts required to capture the flow regimes and stage frequencies in probabilistic terms and do it again three more times for 2050, 2100, and 2200.

- The procedures do not provide adequate hydrographs required for unsteady and multidimensional flow analyses and interior flood analyses with respect to the Delta.

The analysis in the Flood Hazard TM was not intended for transient or multidimensional analysis. See the Water Analysis Module (WAM) TM for details on the modeling.

- The results presented are not accurate enough for the sizing and designing of Corps levees, or for FEMA levee certification analysis.

The flood hazard modeling was not intended for design purposes; it was only designed to provide input to the risk analysis. FEMA certification requires protection against a specific event at a specific location, not a specific inflow into the Delta.

It was never the intent for this study to support any design and we recommend it not be used for design. This is a risk study to assess the vulnerabilities of the system and estimate their probability of failure and the consequences of these failures.

- While the procedures applied for estimating flow-frequency curves associated with the four climate change scenarios are logical, the assumptions and data used do not enable consideration of different reservoir and system operations strategies to be studied. These strategies will need to reflect changes in the snow pack and runoff predicted by the climate change models (see *Climate Change Technical Memorandum*). The assumption that the 23 large watersheds' 100-year (or other) frequency flows can be added together to produce the 100-year Delta flow is invalid. Furthermore, there is no documentation of the assumptions, procedures, and results of the climate change analyses.

The Flood Hazard TM has been updated to provide a more accurate description of the procedure followed. Although future reservoir operations may be different than they are today, the purpose of the flood hazard analysis was not to analyze reservoir operations, but to estimate how the flood frequency curve may change in the future. It would be speculative to try and operate the reservoirs under future, uncertain conditions and would be unlikely to provide a better, more certain estimate of the future flood frequency needed for the Risk Analysis inputs.

We agree with the first point raised, we do not explicitly include reservoir operation for the reasons cited in the previous response on modeling upstream facilities.

We do not iterate the flood model for each flood event analyzed. We have rather used the first results from the flood model (frequencies and associated stages) and calculated the probability of levee failure. After the levees breach, then we use the WAM model to track the reservoir releases (CALSIM model) and the hydrodynamic changes (RMA model) in the Delta post- event and during repair.

In the technical memoranda's comments and replies to comments, the authors of DRMS Phase I address these issues sufficiently. Other specific concerns and comments on this section follow:

There are much longer records for some of the gages in the basin than the 1955-2005 data the authors used. This is especially of concern because there were quite variable flows in some of the early 20th century records. If there is some reason for limiting the flow analysis to this shorter record, the authors need to explain why.

The 50 years of data used in this analysis were selected because the data were readily available for all major delta inflows. (Section 2.2 Page 2)

They state that, " [...] it is believed that changes related to reservoirs and watershed development are associated with water supply and environmental flow releases from the reservoirs and have minimal impact on flood inflows into the Delta" (page 7-1). The Sacramento-San Joaquin watershed is one of the most regulated, large-scale watersheds in the world. The overall effects are shown in the figures below from Kondolf (U.C. Berkeley).

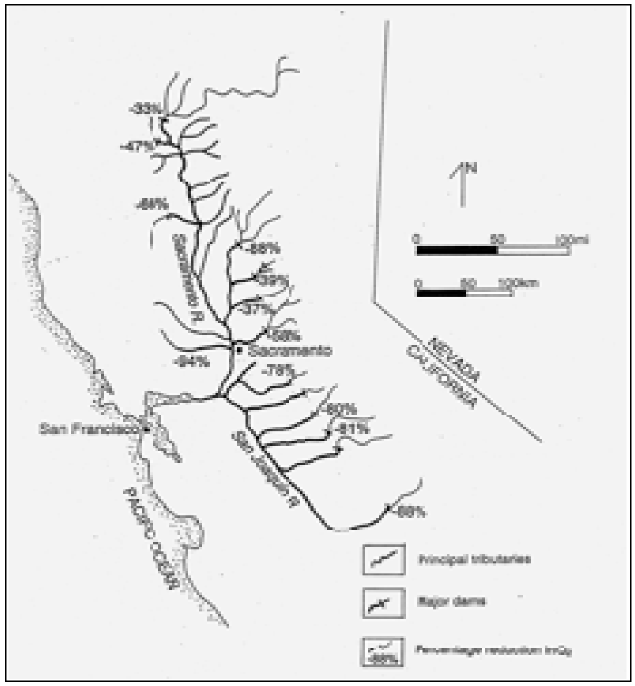

Figure 1: Watershed effects, Kondolf.

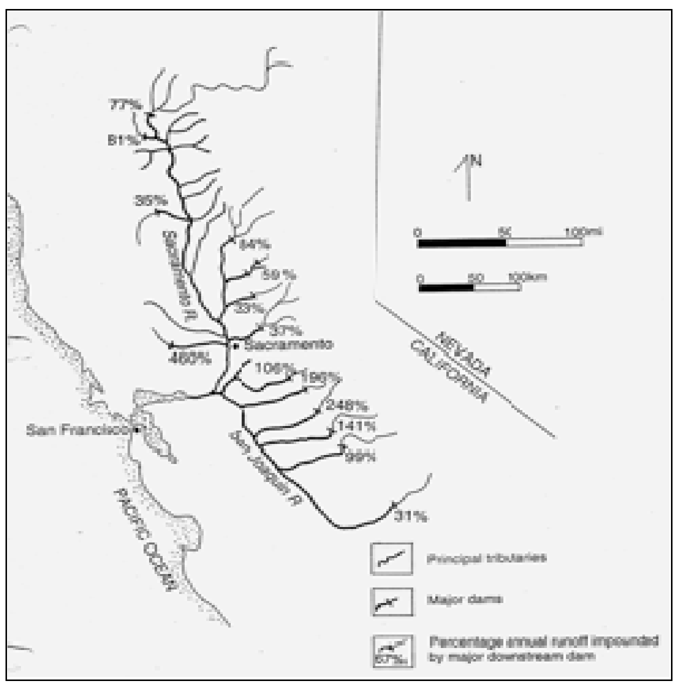

Figure 2: Watershed effects, Kondolf.

> These figures show that flows have been reduced in the main rivers from 33-94% and the percentage of annual runoff impounded behind dams ranges from 35-460%. That this large amount of storage and diversion does not affect flood flows seems highly unlikely. The analyses that they do on the Oroville Dam to show that dams do not effect the hydrograph is not convincing. The record of pre-dam flow is too short (12 years) to capture variability from potential drivers on flow, like ENSO and PDO. Also, looking at Oroville alone ignores the system. Shasta Reservoir is the 9th largest reservoir in the country. It was completed in 1945, so any effect it has on Sacramento River flow would be well before their records that start in 1955. Then there are the inter-basin transfers from the Trinity River into the Sacramento River. It is not clear how it is possible that the peak flows are not affected by all the dams and water diversions in the basin (e.g., look at the number of diversions on their maps in the DRMS *Phase I Report*).

The text will be modified to better reflect the intention of the analysis of reservoir effects of flood flows into the Delta. During the 50 years of data used in the analysis several reservoirs were constructed on the Sacramento and San Joaquin river systems. If construction of the reservoirs had a significant effect on flood flows into the Delta it would not be possible to use the entire 50-year record. In that case we could only use that portion of the record that occurred after construction of the last significant storage project. This would eliminate about half the data. The intention of the analysis is to show that the entire data set could be used as is, without adjustment. The text will be modified to remove the statements that the reservoirs do not provide flood control benefits as that was not the intention. (Section 2.4.1, Page 3)

The modified section of the TM now describes the statistical differences between pre and post- dam construction flows in the Sacramento and San Joaquin rivers. Results of an Anova analysis between the pre- and post- dam eras have been added to the report. The analysis indicated that at the 5% significance level there is no statistical difference between the pre- and post- dam construction peak annual flows. A figure comparing the temporal distribution of the largest events on record was also added, providing additional verification that the general nature of the flood flows into the Delta has not obviously changed over the 50-year period of record. (Section 2.4.1 pp 6-7)

The comments from a USACE reviewer (Kerr) of the technical memorandum also capture these concerns:

> Investigation assumes New Melones and Oroville dams have no significant impact on Delta inflows. This assumption will have a significant impact on the analysis – suggest either rethinking this approach or quantifying the impacts. If, "the average number of days per year with high Delta inflows from SJR is greater during current conditions [record reflected with regulation]" then NML is impacting Delta inflows (more comments below in Section 2.3, paragraph 4). This assumption appears to be in conflict with a statement made in Section 6.1 that "[…] estimated inflows into the Delta in some streams during some storm events may be significantly attenuated by reservoirs[…]"

The discussion in Section 2 on the effect of reservoirs on flood flows into the Delta was used to decide if all 50 years of available data could be used in the analysis or if only data collected after construction of New Melones could be used. Before the analysis it was hypothesized that the reservoirs would decrease flood flows into the Delta and therefore there would be a noticeable decrease in the size of inflows into the Delta after construction of the reservoirs. As described in Section 2, that did not seem to be the case, so it was decided that all 50 years of data could be used in generating the frequency distribution of flows into the Delta. (Section 2.4.1, Page 3)

> Section 2.3, paragraph 4: I believe the assumption that ORO and NML have no impact on Delta inflows is incorrect. The comparison made is over simplified and misleading. Simple comparisons between regulated and unregulated frequency curves contradict this assumption.

The analysis is simple yet it does indicate that the reservoirs have not had the effect on Delta inflows that might be expected. The purpose of the analysis is not to determine the level of impact of reservoir operations on flows in the tributaries to the Delta but determine if the use of 50 years of data that encompasses an era of dam building is reasonable. The analysis indicates that the use of the 50-year data record is reasonable for the purpose of the Risk Analysis. (Section 2.4.1, Page 3)

> Section 2.3, paragraph 5: the suggestion that "fewer peak daily inflows would be expected after the addition of reservoirs in the watersheds if the reservoirs were reducing flood flows" cannot be directly supported without a statistical comparison of reservoir inflows, storm patterns, and ungauged contributions.

We disagree with this comment. It is not unreasonable to anticipate that the construction of reservoirs will reduce peak flood flows downstream of the reservoirs. That is often why they are built.

The authors make another statement of concern, "although the total volume of available flood control storage in the watersheds during the flood events is not known, it is possible that runoff preceding the peak day filled whatever flood control storage was available and inflow into the reservoirs was not significantly greater than outflow on the peak day." This is also an unsubstantiated statement. The storage in all the reservoirs in the basin is known (most can be obtained real-time). The paragraph that follows this is also unsubstantiated, that reservoirs only provide a portion of the storage in floodplains. It may have been true in the long-distant past that the Sacramento and San Joaquin rivers had vast floodplains (before European colonization) that stored tremendous amounts of water, but that certainly is not the case now. Nearly every river in California is separated from its floodplain by levees. This extends well into the upper reaches of the watersheds and certainly is the case for all the lowland river channels.

It is possible to look back at the data and determine what the available storage was for a given historic flood event. It is not possible to look forward and predict what storage will be available for an unknown future event. It may also be true that nearly every river in California is separated from its floodplain by levees. But it is during the large flood *events that levees fail and floodplain storage becomes available. In many cases it is not the size of the storm above the reservoirs that determines the size of inflows into the Delta, but the capacity of the channels feeding the Delta to convey that flow to the Delta. The larger the storm the more likely levees will fail somewhere in the system and reduce the flows into the Delta. However, as we said, the intent of the analysis was not to describe the flood control capabilities of the reservoir system in California but to determine if it was possible to use the entire 50-year dataset.*

This section contains a large number of these types of problems. We will list them without explanation because of the lack of time:

Arbitrary 200,000 cfs cutoff to eliminate non-storm events – unsubstantiated and certainly arbitrary and effects the outcome of analyses (see USACE comments for details). Although they say in their reply to this comment that this has been removed, it is still in the report. This implies they have not made changes they say they have in response to reviewers.

The 200,000 cfs cutoff was reduced to 80,000 cfs for purposes of calculating the distribution of flows in each tributary for a given total Delta inflow. Although a rigorous analysis was not undertaken it was felt that the distribution of flows in the major tributaries to the Delta could be divided into two populations; distributions that represent large storm events, and distributions that represent small storm events and non-storm periods. We were only interested in the storm event data and therefore wanted to eliminate from the dataset those flow distributions that represented non-storm periods.

Figure A, attached, shows a plot of daily average flow from October 1, 1955 to September 30, 2005. A line representing 80,000 cfs is also shown. Using a cutoff of 80,000 cfs captures all the significant storm events and excludes the small and less significant events. It is true that picking a value such as 80,000 cfs is arbitrary and could affect the outcome. But a review of Figure A shows that picking any flows from about 60,000 cfs to about 140,000 cfs would not have made a significant difference in the outcome. Not picking any cutoff value would have affected the outcome by trying to develop a relationship that represented both populations (storm and non-storm). This would likely result in a less reliable relationship for storm events than was used in the analysis.

Regression of total flow to individual river flows oversimplifies the system, e.g., assumption that Sacramento River always has 85% of flow. This is not supported by the data and plots presented.

It was not assumed that the Sacramento River is always 85% of the flow. It was stated that on average the Sacramento River provides 85% of the inflow to the Delta. The actual inflow used in any given scenario was calculated from the logistic regression that was developed as described in Section 4 of the Flood Hazard TM. The regression relationships have associated with them a mean square error for the regression so the inflow from each tributary could be calculated for any selected confidence limit.

It is not at all clear why they did not use existing work. Much work has been done by USACE, etc. on the flood stages of rivers throughout the region. They again cite no previous work and do not put their work in context.

We are not aware of any other studies by the USACE or others on a probabilistic risk analysis of levee failure in the Delta. The flow and stage data and procedures developed in this study were specifically developed as inputs to the risk analysis. We did review the USACE Comprehensive Study. The purpose of that study was considerably different from the purpose of this study and therefore the information contained in the report did not appear to be relevant.

It is worth noting that the purpose of this study was not to develop frequency information on stages in the Delta. The purpose of the study described in the Flood Hazard TM was to develop a relationship for flood stages in the Delta for a given occurrence probability of Delta inflow.

For the given Delta inflow the stage everywhere in the Delta was predicted. The probability of those stages occurring (or of being exceeded) may or may not be equal to the probability of occurrence of the Delta inflow and likely would be different for different parts of the Delta. The procedures used in the risk analysis did not require the selection (or knowledge) of the probability of occurrence of a particular stage in the Delta. This is a departure from typical flood studies and that distinction helps explain why no other studies were identified as having relevant information.

The authors do not cite sources of data or have references to a website. They need complete references to all data used so that the reader can obtain it.

There is a major difference between the FEMA 100-year flood elevation and the authors determination. What are the causes of these differences? In general, their floods are much higher in about half of the Delta, especially the south end. They give no discussion of this. This is a very big deal. For example, Stockton is 0-10 feet from FEMA and 15-20 feet from their analyses. Those are huge differences and they need to be explained because they affect all aspects of their hazard (and ultimately risk) determination.

FEMA 100-year flood is a single deterministic water surface elevation in the Delta. In theis risk analysis each flood frequency (10-year, 20-year,…, 100-year etc.) have multiple surface elevations associated with it. Comparisons with Corps stage curves and historic data will be added in the revised report.

Throughout the report, the authors present information and make statements that are not attributed to a source. This is very frustrating because the validity cannot be determined without citations or sources.

Please provide the specific location of those statements so we can address them. All the specific comments below have been addressed.

Another very important aspect of long-term flow is the past (late Holocene) record. There have been major changes in flow over the last few hundred to few thousand years. There is no reason to not expect these to occur in the future, but there is no mention or discussion of this in the "flooding" section. This is as important (maybe more so because it is data and not model output) that the projections from climate models used to make future predictions of flow. This is a major oversight in this analysis that needs to be addressed or discussed.

We are only considering flood risk in the next 200 years. In the thousands of years more changes will take place. In the late Holocene the hydrology was certainly very different from now when most of the rivers are damed and flow are regulated. These changes are beyond the scope of our work. We will attempt to describe the changes that have occurred in late Holocene in the Geomorphology TM.